

NASA-TM-88447

NASA-TM-88447 19860018625



NASA TM-88447

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NASA TM-88447

WALL EFFECTS IN WIND TUNNELS
J.P..Chevallier and X. Vaucheret

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Translation of "Effets de parois en soufflerie, O.N.E.R.A.,
Report No. T.P. 1983-143, presented at the 20th Colloquium on
Applied Aerodynamics of the AAAF, Toulouse, France, November
8-10, 1983, pp. 1-31.

STANDARD TITLE PAGE

1. Report No. NASA TM 88447	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle WALL EFFECTS IN WIND TUNNELS	5. Report Date July 1986	6. Performing Organization Code
7. Author(s) J.P. Chevallier, and X. Vaucheret	8. Performing Organization Report No.	10. Work Unit No.
9. Performing Organization Name and Address Leo Kanner Associates Redwood City, CA 94063	11. Contract or Grant No. NASW-4005	12. Type of Report and Period Covered Translation
12. Sponsoring Agency Name and Address National Aeronautics and Space Adminis- tration, Washington D.C. 20546	14. Sponsoring Agency Code	
15. Supplementary Notes Translation of "Effects de parois en soufflerie", O.N.E.R.A., Report No. T.P. 1983-143, presented at the 20th Colloquium on Applied Aerodynamics of the AAAF, Toulouse, France, November 8-10, 1983, pp. 1-31		
16. Abstract A synthesis of current trends in the reduction and computation of wall effects is presented. Some of the points discussed include: (1) for the two-dimensional, transonic tests, various control techniques of boundary conditions are used with adap- tive walls offering high precision in determining reference conditions and residual corrections. A reduction in the bound- ary layer effects of the lateral walls is obtained at T2; (2) for the three-dimensional tests, the methods for the reduction of wall effects are still seldom applied due to a lesser need and to their complexity; (3) the supports holding the model of the probes have to be taken into account in the estimation of perturbatory effects.		
17. Key Words (Selected by Author(s))	18. Distribution Statement Unclassified-Unlimited	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 22.

484-19932#
(ORIGINAL)
N-156,157
N86-28097#

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WALL EFFECTS IN WIND TUNNELS

by J.P. Chevallier and X. Vaucheret

INTRODUCTION

/3*

The recent first commercial operation of the NRF high Reynolds number wind tunnel (NASA Langley) [1] , the European ETW wind tunnel project [2] and the continuous request of manufacturers for more specific test conditions in existing installations have led to the creation of different work groups to study the problem of wall effects from the three-fold standpoint of their determination, their reduction and their correction. We may mention in particular an AGARD work group under the auspices of the "Wind Tunnel Testing Subcommittee of the Fluid Dynamics Panel" [3], and the GARTEUR action groups [4]. The most important results were also presented during the following meetings:

- AGARD-FDP Meeting at London on May 19, 20, 1982 (17 reports on wall effects in wind tunnels) [5];

- AGARD FMP Meeting at Smyrne on October 11 to 15, 1982 [6];

- Working sessions on "the reduction and correction of wind tunnel wall effects" NASA Langley Research Center January 25-26 1983 [7].

- 53rd AGARD FDP Meeting on "Wind Tunnels and Testing Techniques" at Cesme on September 26 to 29, 1983 where 36 reports were presented, particularly that of Bionion and Kraft [8], presenting the conclusions of the 1982 meeting at London [5].

Of all studies presented, our purpose is to reveal which of these are current trends and to specify our own practices. To accomplish this, we shall first examine the means currently used to reduce wall effects, then recent methods of calculating these effects, because the two problems are now intricately interrelated.

It seems that there is a quasi general agreement on the need to use measurements of the speed field in the vicinity of the walls to calculate interferences. Measurements of the same type will be used for testing the boundary conditions when we try to minimize these interferences.

In the second part the methods are applied to industrial wind tunnels based on parietal measurements so as to test the representation of the model and its support.

1 - VARIOUS METHODS FOR REDUCING OR CALCULATING WALL EFFECTS

1.1 - REDUCING WALL EFFECTS

It is generally achieved because the term "adaptive walls" is used. It is a vague term covering highly diverse practices using for example:

- permeable walls (perforated walls with variable porosity, fractionated suction chambers, controlled back-pressure; changing slits with valves or counterplates; transversal flaps),

- flexible solid walls.

/4

Various devices for measuring the speed field are combined with these means of testing the transversal flow component: isolated probes, longitudinal tubes fitted with pressure taps, laser velocimetry, parietal taps. We will limit ourselves to a brief description of operational systems, the results of which are published and to the most advanced projects, primarily for two-dimensional testing. The characteristics reduced in terms of test section height (table 1) facilitate comparisons.

-Wind Tunnels With Perforated Walls and Multiple Chambers

The first developed at CALSPAN based on Sears' ideas [9] has a section 25 cm wide and 30 cm high, walls with normal perforations (22.5% opening) with 8 lower chambers and 10 upper chambers, tested individually. Measurements of the flow speed and direction on the control surface, performed at the beginning with clinometric probes now are due to the calibration of longitudinal tubes equipped with 2 rows of pressure taps arranged over opposite generators. These tubes, installed over a rotary support, should enable measurements to be performed on a cylindrical control surface for the extension of three-dimensional flows (Wind tunnels 1T, then 4T of AEDC) figure 1.

-Wind Tunnel With Slits and Multiple Chambers

At the center of AMES [10], a $25 \times 13 \text{ cm}^2$ wind tunnel has 6 suction compartments for each wall. These compartments are in turn divided widthwise into 3 chambers for a three-dimensional adaptation. The measurement of 2 disturbance speed components on one control surface is replaced by the use of 2 control surfaces with measurement of the one cross-component using a laser velocimeter.

-2D Wind Tunnels With Solid Flexible Walls

At the University of Southampton, the TSWT (Transonic Self Streamlining Wind Tunnel) has a $15 \times 15 \text{ cm}^2$ square section and a very long test section (1.12 m) whose upper and lower walls are each shaped using 20 electric actuators with a similar number of parietal pressure taps [11]. As such the wind tunnel was used for two- and three-dimensional testing to determine whether the disturbances to be measured on the walls of these are difficult to obtain with precision (figure 1).

At the Technical University of Berlin [12], the T.U.B. wind

tunnel has a $15 \times 15 \text{ cm}^2$ square section with two flexible walls over 0.69 m each shaped by 8 direct current actuators with a 25 mm path and equipped with some 20 pressure taps.

At CERT at Toulouse, the T2 wind tunnel [18], which was the subject of 2 reports [13, 14] has over its competitors the advantages of one order of magnitude at least with respect to the Reynolds numbers ($0.37 \times 0.38 \text{ m}^2$ test section and generating pressure 5b) and an excellent relative precision in the knowledge of wall shapes (using potentiometers of about 0.05 mm) and speed distributions (with 91 pressure taps on each wall). By vectorizing the program for calculating the virtual field and optimizing the relaxation factors reducing the time required for adaptation during a gust of a few tens of seconds.

In addition to these advantages, the T2 wind tunnel has a relatively short test section (table 1). What can we conclude about the precision of the reference conditions obtained in these conditions? We shall return to this essential point after a brief review of the new methods of assessing wall effects. It should be pointed out that an attempt has been made to compensate for lateral boundary layer effects using reliefs made by gluing paper cut out in the shape of level lines [15]. This procedure finds its justification in recent CEAT tests [16] which show the existence at the root of the model two small counter-rotative vortices, very different from the modelization proposed by Preston [17].

3D Wind Tunnels With Flexible Walls

At the NASA center of Wright Field a $9' \times 9'$ test section (i.e. about $23 \times 23 \text{ cm}$) operating under 4b has 2 flat side walls whereas the other two are made up of flexible rods with alternating circular and triangular sections activated by some 100 actuators. No measurement was performed on the walls [3].

At the Technical University of Berlin [12] a second test section, with an $18 \times 15 \text{ cm}^2$ octogonal section, is used for 3D tests. The feasibility of such tests was demonstrated recently in an operation at Cesme in September 1983 (figure 3), despite the small deformations to be achieved (of the order of one mm).

At DFVLR, in the advanced project, Dehnbare Adapative Mebstrecke (DAM) the circular test section was made up of an elastic tube 800 mm thick whose diameter was stretched into 8 sections by 8 actuators [12] (figure 5).

1.2 - NEW METHODS OF CORRECTING WALL EFFECTS

This was the title, in singular form, of a report presented at the 14th Symposium of Applied Aerodynamics at Toulouse in 1977 [19]. We still use this name for methods which have multiplied for 6 years and whose common points is to call on measurements made on walls or in their vicinity. Created from the necessity of being applicable to adaptive, but not perfectly adapted walls, this type of method has for conventional walls the advantage of eliminating certain controversial assumptions on lineary boundary conditions [18, 20].

Without going into too much detail, we may mention the following methods in the order they appeared:

Kemp: the unknown intensity of the singularities arranged at the walls and at the location of the model is determined to satisfy with speed measurements on an equal number of control points, on the model and at the walls, by resolving the linear system formed with the corresponding impact factors. The parietal singularities thus defined contribute alone to the interferences under investigation.

-Smith [25]: the NLR I method differs from that of Kemp only

in the limitation of the unknown singularities at the wall, the model being represented by given singularities, functions of its geometry and of overall lift and drag measurements.

Capalier et alii [19]: in contrast to the two aforementioned methods the formulation expressed in terms of integrals of the speed deviations measured at the walls and calculated for the model avoids resolving the linear system and therefore eliminates the consequences of random errors in the measurements. This method applies not only to the two-dimensional case, but also to three-dimensional flows in test sections with a rectangular section and flat side walls.

Swada [22] presented a very similar method which he recently applied to two-dimensional unsteady flows [37].

Mokry and Ohman [23]: Dirichlet's problem for the axial speed inside the surface upon which boundary data are collected is solved in the form of a Fourier-Bessel series for three-dimensional cases. Their coefficients are obtained using rapid Fourier transforms.

For corrections calculated on the axis of the test section, a cylindrical control surface may be used no matter what the shape of the test section has.

Mokry compared these methods [24] on a two-dimensional test case and showed that [19] and [23] gave identical results and [22] and [25] deviated only very slightly.

Ashill [27] as well as Smith in the unpublished NLR II method avoiding the use of the model which may be delicate in the presence of supersonic or separation regions in the flow. They should therefore use measurements of the two disturbance components in the vicinity of the walls.

All of these methods are of the linear type and are limited for this reason below $M = 1$. Also they implicitly assume that the boundary conditions are homogeneous enough for the measurements near the walls to be significant.

For any method used, the precision required in knowing the two disturbance components will be brought to light through the explicit formulation of the speed and incidence corrections based on the relative longitudinal disturbance component u [19] cu , according to the so-called conjugated formulation [28] on the relative transversal component. By letting u_i and v_i be the wall interference components at the center of the test section and by simplifying the formulas given in [18] based on an empty test section.

$$\begin{aligned}
 (1) \quad u_i(x, 0) &= \frac{1}{\beta h} \int_{-\infty}^{\infty} \frac{u(\xi, h/2) + u(\xi, -h/2)}{2 \operatorname{Ch} \pi(\xi - x)/\beta h} d\xi \\
 (2) \quad v_i(x, 0) &= \frac{1}{h} \int_{-\infty}^{\infty} \frac{u(\xi, h/2) - u(\xi, -h/2)}{e^{2\pi(\xi - x)/\beta h} + 1} d\xi + C \\
 (3) \quad u_i(x, 0) &= \frac{1}{h} \int_{-\infty}^{\infty} \frac{v(\xi, h/2) - v(\xi, -h/2)}{e^{2\pi(\xi - x)/\beta h} + 1} d\xi + C' \\
 (4) \quad v_i(x, 0) &= \frac{1}{\beta h} \int_{-\infty}^{\infty} \frac{v(\xi, h/2) + v(\xi, -h/2)}{2 \operatorname{Ch} \pi(\xi - x)/\beta h} d\xi
 \end{aligned}$$

No problem is raised by using formula (1) because it was shown that it tolerates the truncation of the integration terminals owing to the rapid decrease in the impact function and the fact that it eliminates the reference errors. The same is true for formula (4) in regard to incidence. Conversely, for formula (2) it is necessary to determine the constant C . It is zero if we adopt as reference a flow direction which is sufficiently upstream so that the difference $u(\xi, h/2) - u(\xi, -h/2)$ is zero. It also shows in the nucleus of the integral a speed difference which is delicate to measure.

Based on these formulas we therefore conclude that to apply the so-called new correction methods it is necessary to know, at a right angle with the model, the speed vector in modulus and direction, in the vicinity of the walls, with a precision of the same order of as that required on so-called "upstream infinity" conditions.

1.3 - DETERMINING THE REFERENCE CONDITIONS

The crucial importance of determining these conditions accurately was recently recalled in a report under the "Wind Tunnel Testing Techniques" Committee of AGARD-FDP which set forth the requirements of airplane manufacturers with respect to wind tunnels [29].

The investigation of an error limited to $\Delta C_x = 0.0001$ leads to $\Delta M = 0.001$ and $\Delta \alpha = 0.01^\circ$ in regard to the Mach number and the incidence. This goal, which seems a challenge, actually deserves considerable effort because in other sources [30] it is shown that a 1% gain in the cruise drag (considerable only in these conditions) is profitable even if we have to quintuple the number of aerodynamic tests of a transport aircraft.

How can we possibly know the direction and speed of an "infinite upstream" flow in a wind tunnel with such accuracy?

Excluding the support effects, which will be discussed in the second part, and remembering that we have to know the direction and speed on a control surface with the same precision, by examining the errors inherent to the various procedures for measuring the flow disturbance components (laser, clinometric probes, etc), here at ONERA we think that there is only one valid procedure: using deformable solid walls where the quality of the surface condition and pressure taps is equal to that obtained on airfoils and position measurements showing the shape of the wall (which will be

corrected for the boundary layer displacement thicknesses).

Among the wind tunnels which try to achieve these conditions, we see that T2 has a shorter test section, but that it is long enough to define the reference conditions perfectly, given the balance functions discussed above. It has the largest number of parietal pressure measurements and actuators near the model and the best definition of the wall positions. The scope of the displacements is slightly smaller and as a result the dimension of the model is limited. The displacement pitch in other regions is too strong.

In these apparently optimal conditions, has the objective focussed on been achieved? It is virtually impossible to calculate an error: the shapes of adaptive walls are derived by processing an external virtual flow using Green's formula and whose parietal speed measurements are the data. Conversely, the overspeeds at a right angle with the model are also functionals of /8 the slopes obtained by smoothing and interpolation of the measured dimensions. An intrinsic validation was therefore tried by placing the same model (CAS 7 airfoil with a 200 mm chord) over the axis of the wind tunnel and at 80 mm below this axis. By adapting each case, the wall shapes and parietal pressure distributions are totally different [15]. The variation of the lift factor as a function of the Mach number for angles of 0 and 1°, shown in figure 6 on a large scale, shows the dispersion of the measuring points. The latter does not show any systematic deviation due to the difference in testing conditions and it seems small enough for us to be able to conclude that the objective is virtually if not fully achieved. This success in two-dimensional testing leaves promising prospects for extensions to three-dimensional flows provided that all precautions are taken to observe the purity of the flows, the homogeneity of the boundary conditions and the precision of the parietal measurements in the presence of considerably smaller disturbance fields.

2 - WALL AND SUPPORT EFFECTS IN ONERA'S INDUSTRIAL WIND TUNNELS

In wind tunnels not yet equipped with adaptive walls and with magnetic suspensions, it is still necessary to make corrections for wall and support effects to restore as far as possible the results which would be obtained on models in an unlimited atmosphere. There are two types of corrections to be made for the potentials under consideration:

- the wall effects are calculated based on the interference potential promoted by the walls,

- the support effects are the result of the sum of the potential of the supports in an unlimited atmosphere and of the interference potential promoted by the walls.

2.1 WALL EFFECTS

Two methods are currently employed for calculating wall effects. These methods have already been presented.

The first method, called the "conventional method" [31] consists of calculating the potential promoted by the walls by solving a problem whose data are the following:

- the potential of the model in an unlimited atmosphere,

- the boundary conditions on the walls of the test section involving the concept of equivalent uniform wall porosity.

The second method, called the "signature method" [19] allows the potential promoted by the walls to be derived from data consisting of:

- the potential of the model in an unlimited atmosphere,

-the distributions of pressures measured on the control surfaces of the test section (signatures).

These two methods have in common the assumption of a cylindrical test section reaching to infinity, and the necessity of making use of a mathematical description of the model. /9

2.1.1 Mathematical Description of the Model

Since we are referring to a corrective calculation and not a calculation of the flow on the model, the specification of the model is rudimentary: it should include the required number of singularities for the model field to be properly represented at a distance from the model. The best way to control the specification consists of comparing the signatures measured and calculated on the walls of the test section in a configuration with perfectly known boundary conditions: in this case the use of solid walls is unambiguous.

The iterative process (figure 7) is the following: using signature measurements on the walls of a guided test section, in the presence and in the absence of a model, by adding and subtracting we find the parts for the locking and lift terms corresponding to an isolated model. The model specification associated with zero porosity conditions of the walls makes it possible to obtain signatures at the same locations of the test section and to divide them into locking and lift terms. An examination of the differences between calculated and measured signatures makes it possible to check whether the model specification should be improved and in this case which part of the specification, volume, wake, lift is to be altered to be acceptable in terms of manufacturer specifications.

Two examples illustrate the mathematical specifications of the model.

The first example concerns tests on a profile in a flat current in S3MA in a guided test section configuration. An example of the signatures measured in the presence of a profile, then corrected of the readings in the absence of a profile (figure 8) show that the tapping errors were eliminated as well as the effect of the wake comb located downstream. A comparison of the calculated and measured signatures (figure 9) show that the lift description due to two intensity vortices derived from measurements of C_z and C_M is adequate [32]. At zero lift, the description of the volume using a single doublets is also adequate. Conversely, the description of the wake using a single source is increasingly incorrect when Z_z (therefore C_x) increases. This is due to the absence of the tapping by considering the separations in the description. Work is now underway to correct this.

The second example concerns a space model (figure 10) in a 47 m^2 SIMA test section. The description of the streamlined bodies is here a double doublets number of the ratio between the length and diameter of the body. We see that the calculated signatures, in good agreement with the measurements, personalize well the shape of the model: flat signature for the fuselage alone, bulging for the entire spacecraft.

When the mathematical description of the model is considered to be correct, calculations may begin to correct the wall effects.

2.1.2 Signatures Method

/10

As indicated above, this method does not require knowledge of wall porosities. One simply needs to measure the signatures over a control surface so that the wall porosity effects are homogeneous.

In perforated walls, and a fortiori solid ones, these control surfaces are the walls themselves. The duration of the signature measurements does not exceed that of the wake measurements of a

flat current profile. This method is systematically applied to profile testing in S3MA. The corrected results obtained on the CAST 7 profile are in good agreement with those obtained in the test section with adaptive walls of the T2 wind tunnel of CERT/TOULOUSE (figure 11) as well as for the lift curves and for the stability curves of the maximum C_z .

In the case of walls with slits, the signatures may no longer be sampled on the walls. According to a recent publication [20], the signatures should be recorded at a distance from the walls which is virtually equal to the slit pitch. This is a problem for the test section which has a limited number of slits.

2.1.3 Conventional Method

In addition to a correction description of the model, it is necessary in the conventional method to know the wall porosity laws as a function of the Mach and of the generating pressure and to validate the concept of uniform wall porosity.

The reference tests [31] are referred to determine the wall porosity laws. These tests may be obtained by performing tests on the same model, with the same Reynolds number:

- in the same test section rendered guided by the ventilation mask,

- in a test section with such dimensions that the wall effects are negligible.

As far as possible the second type of reference is preferred because it has no limits due to the test section locking and does not require corrections which are high in three-dimensional cases.

The iterative process used for defining the porosity laws is the following (figure 12).

The work always includes an interpolation in M , C_z of the wind tunnel data. The first assessment of the deviations to be reabsorbed by corrections is established in incidence deviations as a function of C_z at a fixed Mach, and in C_x deviations as a function of M for a given C_z .

The deviations of M and C_z between interpolated results, corrected for the reference test and not corrected for the ventilated wall test are introduced into the curve networks established as a function of porosity. This gives the first porosity law. It is used to correct the results of the ventilated wall test. The differences between the interpolated results corrected for both tests are then examined. If these differences satisfy the manufacturer's precision specifications, the work is completed. Otherwise, the process is repeated. In general, three iterations are necessary. If differences still exist, the reasons are investigated. /11

An examination of the pressure distributions measured on the walls of the test section make it possible to define the Mach-incidence limits beyond which the Mach number is greater than 1. In fact, this value is obtained on the ceiling and there is not yet any locking of the test section: the supersonic region on the top skin of the wings reaches the ceiling. The wall corrections are no longer applicable. Figure 13 shows, for a corrected Mach, the limits obtained at SIMA for three slit conditions and at S2MA for 2 homothetic models.

In the case of an S2MA transonic test section, for two used conditions of perforated walls (by opening slide valves by 100 and 55% to modify the porosity), the porosity laws (figure 14) were established by using as reference tests tests on the same model in SIMA with an area 13 times larger than that of S2MA. These laws proved to be correct for full and half civilian aircraft models up to Mach 0.92 and for full military aircraft models up to the limits due to supersonic zones.

In the case of a 20 m² SIMA test section, the porosity laws (figure 14) of 4-slotted or 8-slotted open configurations were defined in the reference for tests performed in closed slotted configuration. These laws are correct up to Mach 0.85.

Beyond this value, there are still differences between the corrected results, obtained for the three test section cases, and an attempt is being made to resolve these differences.

2.1.4 Indirect Signatures Method

One variant of the conventional method consists of basing oneself on the signatures calculation as a function of the porosity parameter assumed to be uniform and by comparison with the measured signatures to derive the wall porosity cartography. This variant was used for the case of the S3MA perforated wall test section. After verifying the correct description of the locking and lift terms in a guided test section, figure 15 shows that for perforated walls, a comparison of the signatures leads to a Q uniform porosity parameter Q of 0.2 on the walls. This porosity is moreover identical to that derived from the overall efforts in a guided reference test section.

In fact, this indirect signatures method is used to check the validity of the wall uniform porosity concept.

In test sections with perforated walls, a porosity test by comparing the measured and calculated signatures has not raised any special problems. As with this case the concept of a uniform equivalent porosity was not handicapped by examining the signatures. The conventional method was retained because it is not penalizing in terms of computer time, after the porosity laws are established. Generally speaking, the more the porosity concept is uniform, the more the mathematical description of models and stings proves to be inadequate. /12

2.2 MODEL SUPPORT INTERFERENCES

Corrections of the Mach number and of the Archimedean thrust brought about by the presence of model supports may be obtained experimentally based on measurements of the K_p distributions at the location which the model fuselage axis would occupy. A clinometric sounding would also make it possible to know the tail unit setting correction due to supports.

To avoid costly soundings, a calculation may be performed. Two methods are used at present.

The surface singularities method begins with a meshing of obstacles in the test section of on its walls. This technique is directly derived from techniques used by manufacturers in an unlimited atmosphere by adding the walls to simulate the contained atmosphere of the test sections. Illustrations of the meshing are therefore borrowed from manufacturers. Figure 16 shows [33] the sting and sting holder in the S5 guided test section of CEAT-TOULOUSE used by DASSAULT-BREGUET. Figure 17 shows the meshing of a Mirage model installed on the wall of the S2MA guided test section and of the device with 6 degrees of liberty to study load trajectories: calculations performed by LE BOXEZ of AMD-BA.

Figure 18 is concerned with the assembly of a civilian aircraft twin sting in a guided test section meshed by AEROSPATIALE. More complex cases including ventilated walls and descriptions of test section ends and upstream parts with tapered section are under study. This method is still complicated to use and requires powerful computers.

A description of test section obstacles using singularities distributed over their skeletons of various shapes has been tried recently by ONERA [34]. The only data are the coordinates of the assembly skeleton and the area rule.

An attempt is made to validate this method in an unlimited atmosphere by comparison with the results of previous more sophisticated methods. Figure 19 shows, in these conditions, a good agreement of the Kps and incidence promoted by an inclined support used in a sabre assembly of the F4 model.

The support description is tested in the guided test section by comparing the measured and calculated signatures. In this case, a description of the model-support system is used. Figure 13/14 shows the case of an ONERA standard model assembled in a straight sting in the S3MA guided-rendered test section. A modelization with 20 doublets for the model and 15 for the sting provide a good agreement of the signatures.

Returning to the case of the F4 model in an S2MA transonic test section, figure 19 gives the Kp distributions on the line which the fuselage axis would occupy for various wall porosities.

We should insist on the relative magnitude of the wall effects and sting interferences. In the case of an S2MA wind tunnel (figure 20), in the perforated wall version with maximum rate, the incidence corrections are zero. The drag corrections resulting from the longitudinal gradients promoted on the support sting and the wall effects are in a 3 to 4 ratio for a civilian aircraft model. The sting interference is more crucial for military aircraft models whose incidences may exceed 40 degrees (and even higher for missiles) [35,36]. Given these high values and the stresses to contain, the volumes of model support mechanisms are such that the wall effects for a well conditioned test section may seem secondary. This real problem, in the absence of a magnetic suspension, deserves to be considered first for future active wall wind tunnels.

2.3 APPLICATION TO INDUSTRIAL TESTING

We now have correct descriptions of models and its supports and of the test section porosity laws. As of now the corrections

are all calculated prior to testing for a specific case of a test section, wall configuration, supports, model.

These corrections (figure 21) include four parts:

- corrections relative to an empty test section obtained from corrected soundings, if necessary, and from the influence of the probe support,

- calculated or measured support interferences,

- corrections of wall effects and of the field impact of the model on the test reference.

In all the computer calculations provide a set of corrections depending on M , C_x , C_z (or incidence) expressed in the form of a table or polynomial laws which are introduced in the wind tunnel calculations to obtained real time corrected results. The correction calculations also provide the total field promoted by the walls and supports, for a Mach distribution and incidence correction on any point of the model. It is easy to know the spin and camber corrections of the wind promoted by the walls and the local M and tail unit setting corrections due to the model supports.

CONCLUSION

/14

The advantage of pressure measurements on the walls of test sections was clearly established for calculations of wall effects. For reasons of convenience associated with the intended use of wind tunnels, these pressure measurements are still performed:

- occasionally in 3d to control the concept of uniform porosity of perforated walls and to check the mathematical descriptions of models and supports in a guided test section,

- systematically in 2D for direct access to corrections,

-imperatively in test sections with adaptive walls,

-finally with suspicion in test sections with slotted walls. The measurements should be performed at a distance from the walls which is technologically difficult to do.

If the advantage of additional measurements of the other component of the local flow on control surfaces is to eliminate any model description, a real problem of measurement precision has not yet been solved.

Optimized test configurations (test section, sting, model) is the result of a compromise between wind tunnel investments, the cost of testing and the quickness with which the results prepared are rectified. In three-dimensional cases, the wall effect levels are reduced by limitations in model size due to the span for civilian aircraft, due to the length for high incidence military aircraft. Small displacements of flexible walls will require greater accuracy in pressure measurements and in the positions of adaptive actuators. Test sections with 3d adaptive walls are still too recent to know their application limits and operating difficulties.

Meanwhile, it is suggested to use adaptations to the main point of a test program. These adaptations may concern:

-models whose manufacturing specifications account for distortions in the flow of conventional walls (as practiced for aeroelasticity);

-walls which should meet specifications using conventional padding whether or not associated with improved ventilation distributions.

In any case, continuous revisions of concepts for minimizing wall effects should follow improvements in the specifications for precision required by manufacturers.

REFERENCES

1. L. McKinney, "Operational Experience with the National Transonic Facility", AGARD Cesme 1983.
2. R. North and alii, "Status Report on the European Transonic Wind Tunnel ETW" AGARD Cesme 1983.
3. R. Dietz, "Wind Tunnel Capability Related to Test Section, Cryogenics and Computer-Wind tunnel Integration", AGARD-AR - 174 April 1982.
4. A. El Senaar, E. Stanewsky, "A Report of GARTEUR Action Group on "Two Dimensional Transonic Testing Methods", AGARD CP 335-5 September 1982.
5. Wall Interference in Wind Tunnels Fluid Dynamics Panel Specialists Meeting", London 19-20, May 1982, AGARD CP 335.
6. T. Bionion, X. Vaucheret, X. Bouis, "Progress in Wind Tunnel Test Techniques and in the Corrections and Analysis of the Results", AGARD CP 339 - February 1983.
7. J.P. Chevallier, "Survey of the ONERA Activities on the Adaptive Walls Applications and Computation of Residual Corrections", Wind Tunnel Wall Interference Assessment/Correction Workshop NASA Langley 25-26 January 1983.
8. T. Bionion, E. Kraft, "A Review and an Update of GDP Specialists' Meeting (London) on Wall Interference in Wind Tunnels", AGARD CPP 348-6 - August 1983.
9. L. Parker, J. Erickson, "Development of a Three-Dimensional Adaptive Wall Test Section with Perforated Walls", AGARD CP 335-17, 1982.
10. E. Schairer, J. Mendoza, "Adaptive Wall Wind Tunnel Research at AMES Research Center", AGARD CP 335-16, 1982.
11. S.W.D. Wolf, I. Cook, M. Goodyer, "The Status of Two and Three-Dimensional Testing in the University of Southampton Transonic Sel Stream Lining Wind Tunnel" AGARD CP 335-15, 1982.
12. V. Ganzer, "On the Use of Adaptive Walls for Transonic Wind Tunnel" AGARD CP 335 - 13 - 1982.
13. Mignosi, Dor, Gobert, "Results of Cryogenic Tests at T2", Report to 20th AAF Symposium, November 1983.
14. Archambaud, Seraudie, "Studies of Adaptive walls With T2", Report at 20th AAF Symposium, November 1983.

- 15 - F. Chevallier, A. Mignosi, J. Archambaud, A. Seraudie, "Adaptive Walls on a T2 Wind Tunnel. Principle, Construction and a Few Examples of Two-Dimensional Results", Aero-spatiale Research no. 1983.4 - July 1984.
- 16 - J. Coulomb, "Clinometric Soundings Downstream from a Profile Between Walls. DRET/CEAT Summary Report 83/1013, August 29, 1983.
17. J. Chevallier, "Three-dimensional Tests on Profiles", 18th Symposium of Applied Aerodynamics by AAF Positions, November 1981.
18. J.P. Archambaud, J. Chevallier, "Use of Adaptive Walls for Flat Current Testing", AGARD CP 335-14, 1982.
19. C. Capelier, J. Chevallier, F. Bouniol, "New Method of Correcting Wall Effects in a Flat Current", 14th Symposium of Applied Aerodynamics. Toulouse 7/9 November 1977 and R.A. no. 1 - 1978.
20. M.C. Firmin, P. Cook, "Disturbances from Ventilated Tunnel Walls in Airfoil Testing", AGARD CPP 348-8. August 1983.
21. W. Kemp, "Transonic Assessment of Two-Dimensional Wind Tunnel Wall Interference Using Measured Wall Pressures", Advanced Technology Airfoil Research. NASA Conf. Publ.2045 - March 1978.
22. H. Sawada, "An Experiment of Lift Interference on 2D Wings in a Wind Tunnel With Perforated Walls", Trans Japan Soc. Aerospace Sci. Vol.22 - 1980 pp. 181-202.
23. M. Mokry, L. Ohmann, "Application of the Fast Fourier Transform to Two Dimensional Wind Tunnel Wall Interference", J.Of.Aircraft Vol.17, June 1980, pp 402-408.
24. M.Mokry, "Evaluation of Transonic Wall Interference Corrections From Measured Wall Pressures", AGARD Working Group. NASA Langley 13/14 March 1980.
25. J. Smith, "A Method For Determining 2D Wall Interference on an Airfoil From Measured Pressure Distributions Near the Walls and on the Model NLR TR 81016 U 1981.
26. J. SMith, "Measured Boundary Conditions Methods for 2d FLOW", AGARD CP 335.9 - September 1982.
27. P. Ashill, D. Weeks, "A Method for Determining Wall Interference Corrections in Solid Wall Tunnels From Measurements of Static Pressure at the Walls", AGARD - CP 335-1 - September 1982.
- 28 - J. Paquet, "Disturbances Caused by the Walls of a Wind Tunnel. Integral Method", Phd Engineering Thesis, University of Lille 6/26/83.

29. F. Steinle, E. Stanevsky, "Wind Tunnel Flow Quality and Data Accuracy Requirements", AGARD AR 184 November 1982.
30. P. Poisson-Quinton, "Ground /FLight Test Techniques and Correlation", AGARD FDP Meeting Cesme Sept. 1983.
31. X. Vaucheret, "Corrections of Transonic Wind Tunnel Walls - Equivalent Porosity", ONERA - Publication No. 1977-3.
32. X. Vaucheret, "Reevaluation of the Corrected Results of the S3MA CAST 7 Profile. Appendix to: A Report of a GARTEUR ACTION GROUP ON TWO Dimensional Transonic Testing Methods", AGARD CP - 335 - London - May 1982.
33. J. Fiat, "Calculation of Lifting Surfaces in the Presence of Nonlifting Bodies in Perfect Incompressible Flows Using the Singularities Method", CNAM Engineering Thesis - Paris 1982.
34. X. Vaucheret, "Improvement to the Calculation of Wall Effects in ONERA Industrial Wind Tunnels", AGARD CP - 335 - London - May 1982.
35. L. Ericsson, J. Reding, "Practical Solutions To Simulation Difficulties in Subscale Wind Tunnels Tests", AGARD CP 348 - CESME - Sept. 1983.
36. X. Vaucheret, "Improvements in Solving the Problems Encountered during High Incidence Testing of Models in Wind Tunnels", AGARD-R-692 - Munich - May 1980.
37. H. Sawada, "A new Method of Estimating Wind Tunnel Wall Interference in the Unsteady Two Dimensional Flow", NAE AN 9 NRC 21274 - January 1983.

Table 1
Wind Tunnels With Controlled 2D Boundary Conditions

Wind Tunnel	Location	Test Section Section: $b \times H$	Length/H	Boundary Conditions Control Nb Points	(paths, Threshold/H	Model C/H
T.S.W.T.	University of South Hampton	15x15cm ²	7.33	20 actuators		0.6 to 1
T.U.B.	Technical University of Berlin	15x15cm ²	4.6	8 actuators	$\pm 0.16 \cdot 10^{-4}$	0.66
T ₂	ONERA-CERT Toulouse	39x37 cm ²	3.5	16 actuators	0.07 10^{-4}	0.3 to 0.5
CALSPAN AEDC	Buffalo Tullahoma	25x30cm ²	4.6	10 boxes (perforated walls)	Longitudinal Tubes 0.3°	0.3 to 0.5
NASA Ames	California	25x13cm ²	5.66	3x6 boxes (slotted holes)	Laser Velocimetry over two 0.05° planes	0.6

Table 2
Main Methods of Calculating Wall Effects Using
Parietal Data

Author	Data Required At Wall	On Model	Resolution Method	Applicability
KEMP [21]	u_p	u_m	n+p sing. distribution on wall and linear model system	2D and potentially 3D
CAPELIER [19]	u or v	Cz,Ca,Cx geometry & measure- ment	Numerical Integration Explicitly or tabulated Impact Functions	2D and 3D in rec- tangular test sec- tion with flat lateral walls.
SMITH [25] NLR I	u_p	Cz,Ca,Cx geometry & measure- ments	Singularities distribu- tions on walls Linear system	2D
SAWADA [22] [37]	u	Represent- ation of model	Fast FFT Fourier Series Green's theorem	2D and 3D with unsteady 2D
MORRY [24]	u	Represent- ation of model	Fast FFT Fourier Series	2D and 3D with cylindrical sur- face control
ASHILL [25] and NRL II	u & v	No repre- sentation	Green's theorem applied inside the control surface	2D and 3D

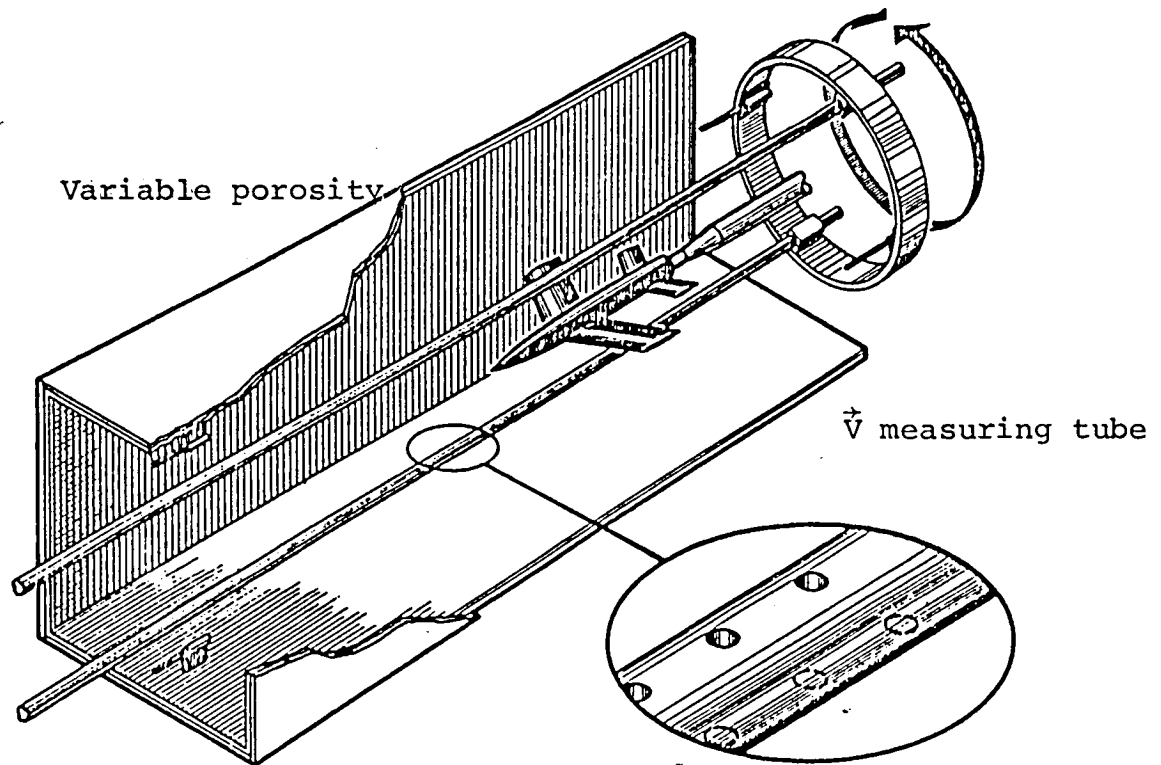


Fig. 1 - A.E.D.C.

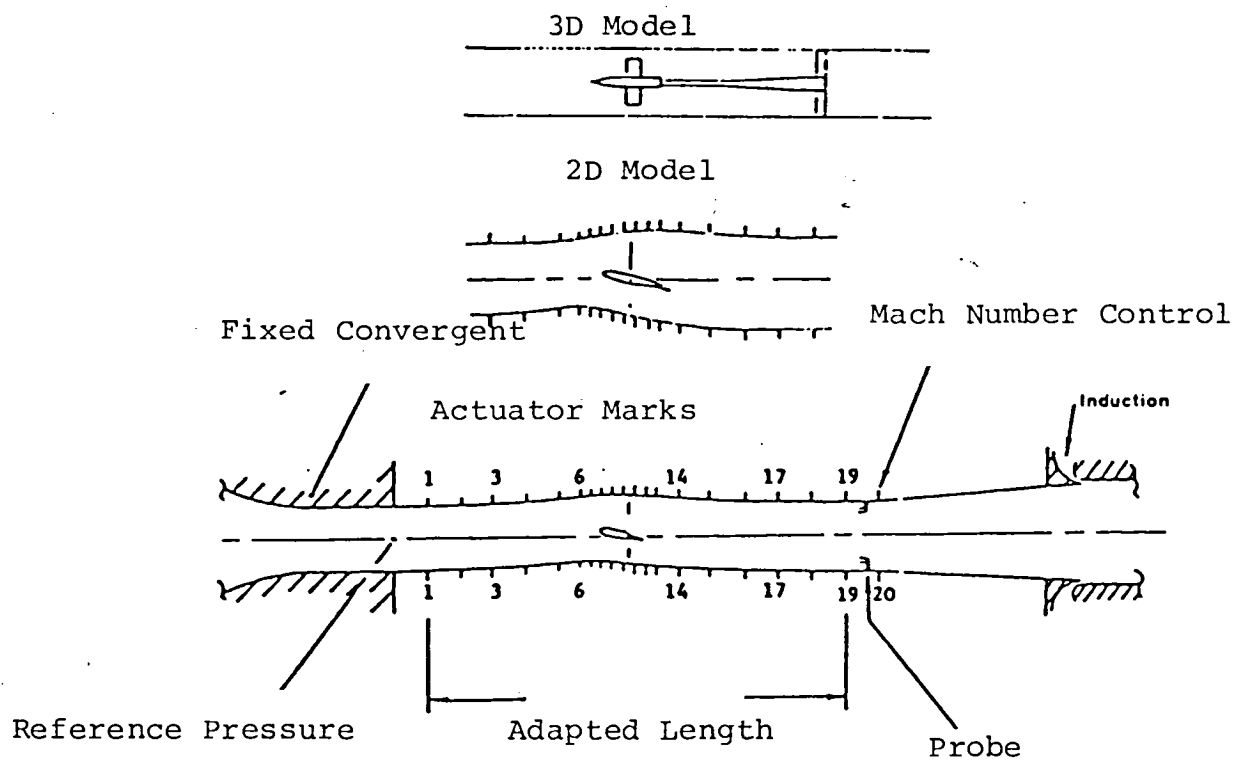


Fig. 2 - Wind Tunnel of Southampton University

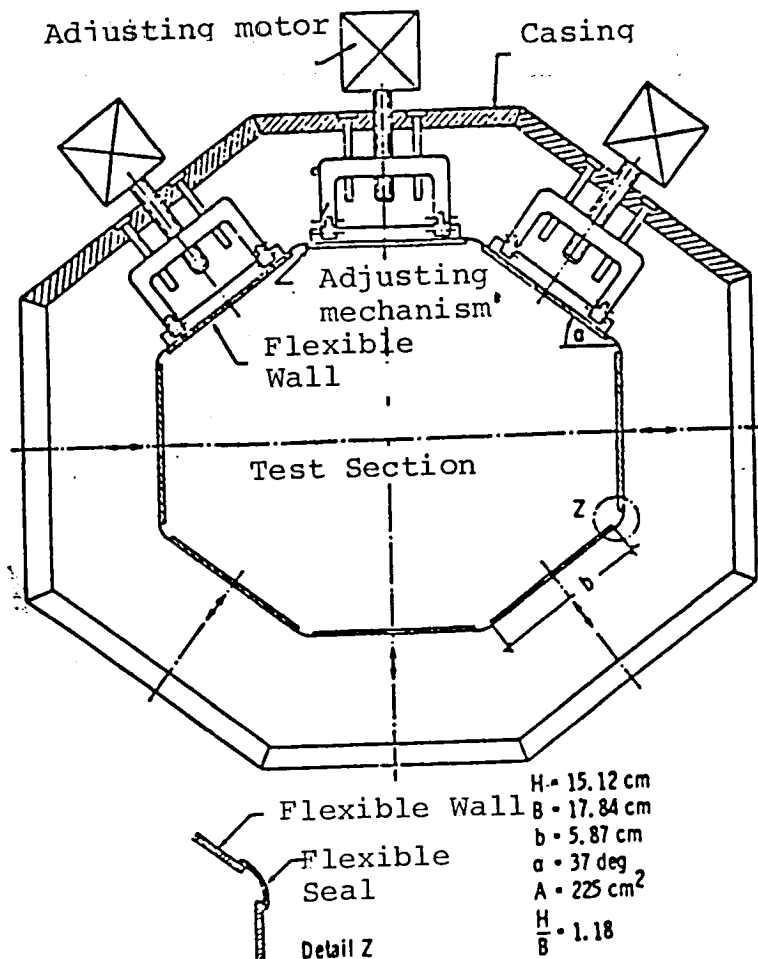


Fig. 3 - University of Berlin Wind Tunnel

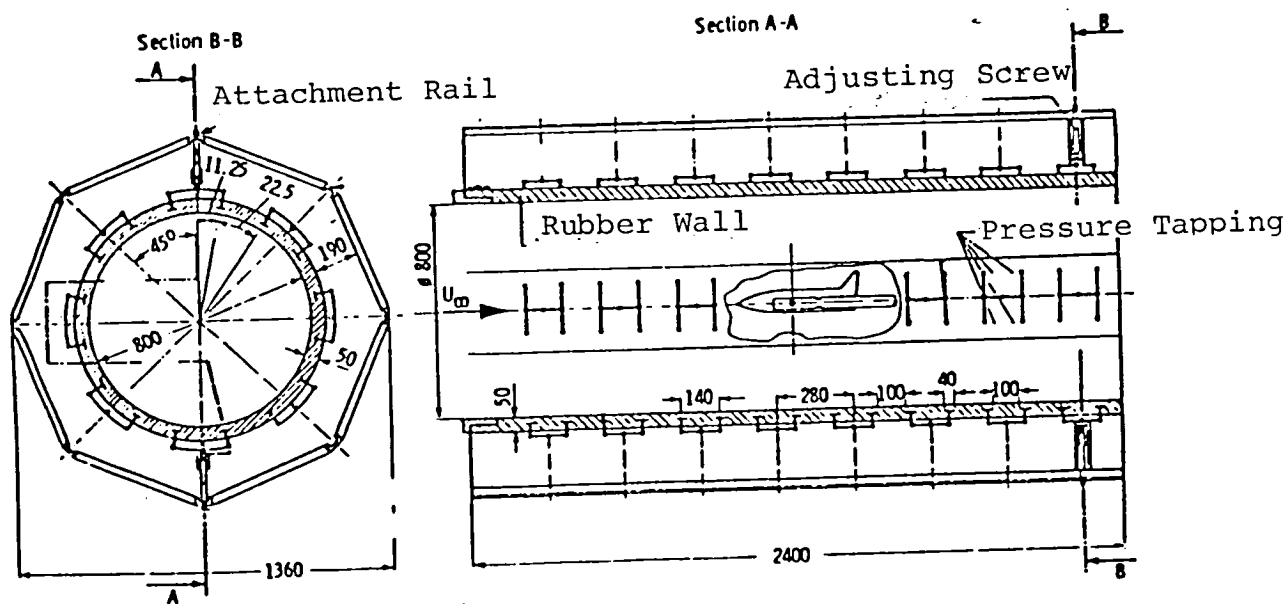


Fig. 4 - DFVLR Test Section Project with Elastic Wall

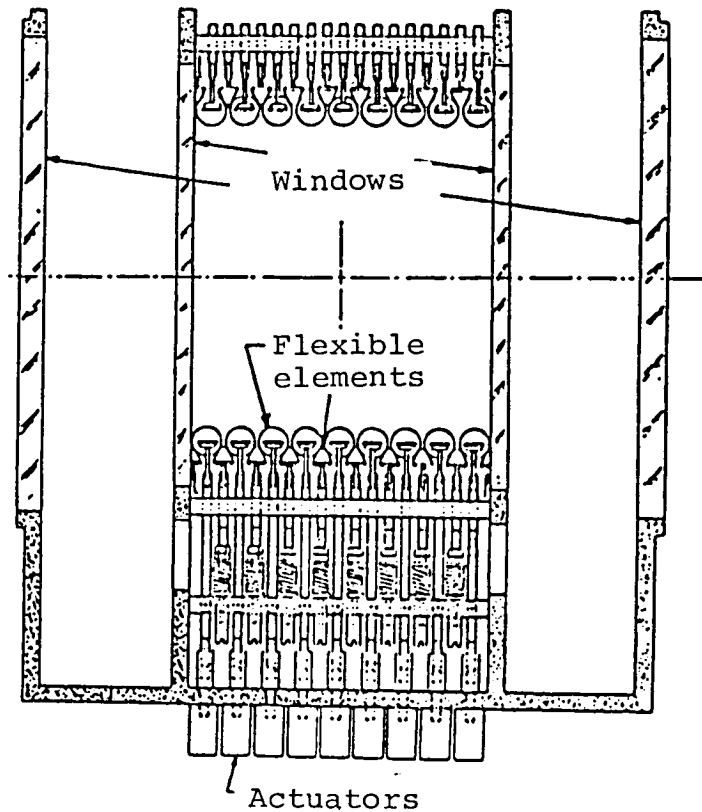


Fig. 5 - AFFDL Pilot Wind Tunnel With Flexible Wall Elements

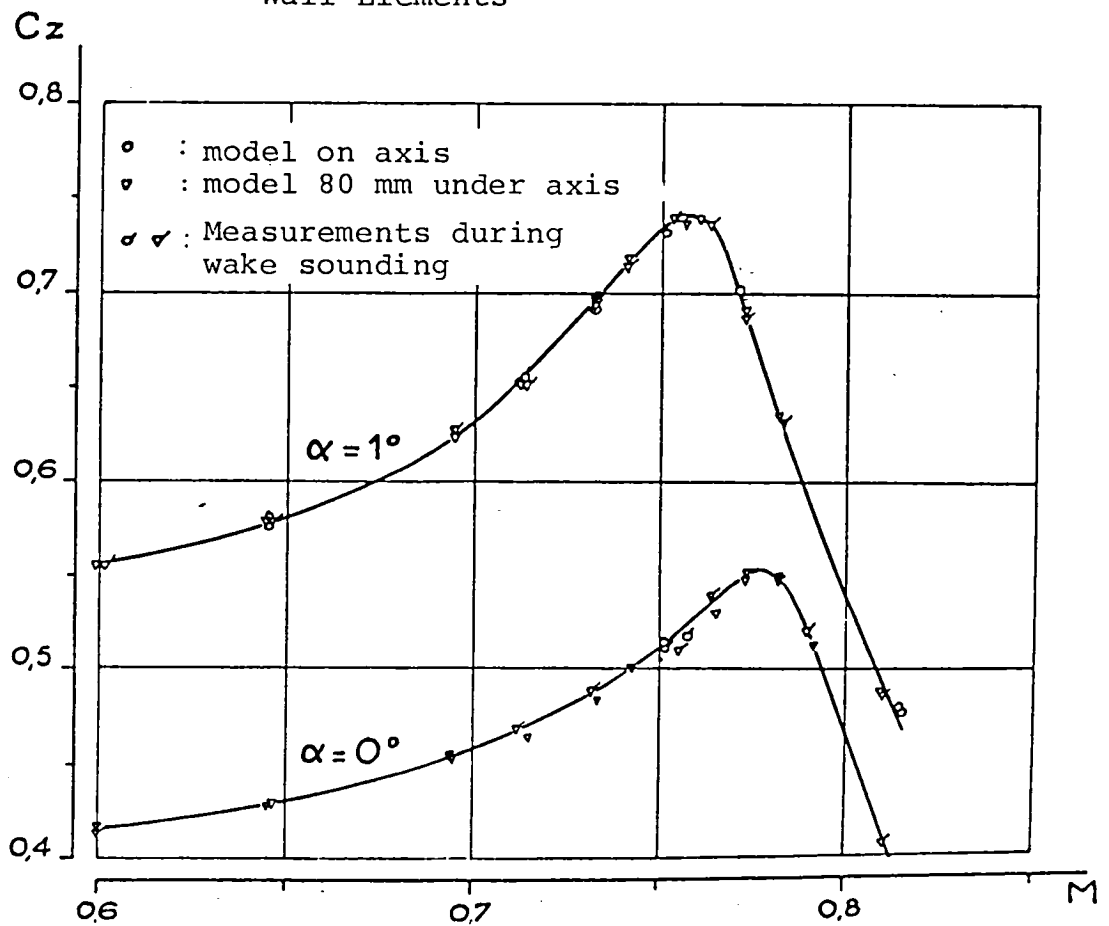


Fig. 6 - CAST 7 Profile. Lift as a Function of Mach Number

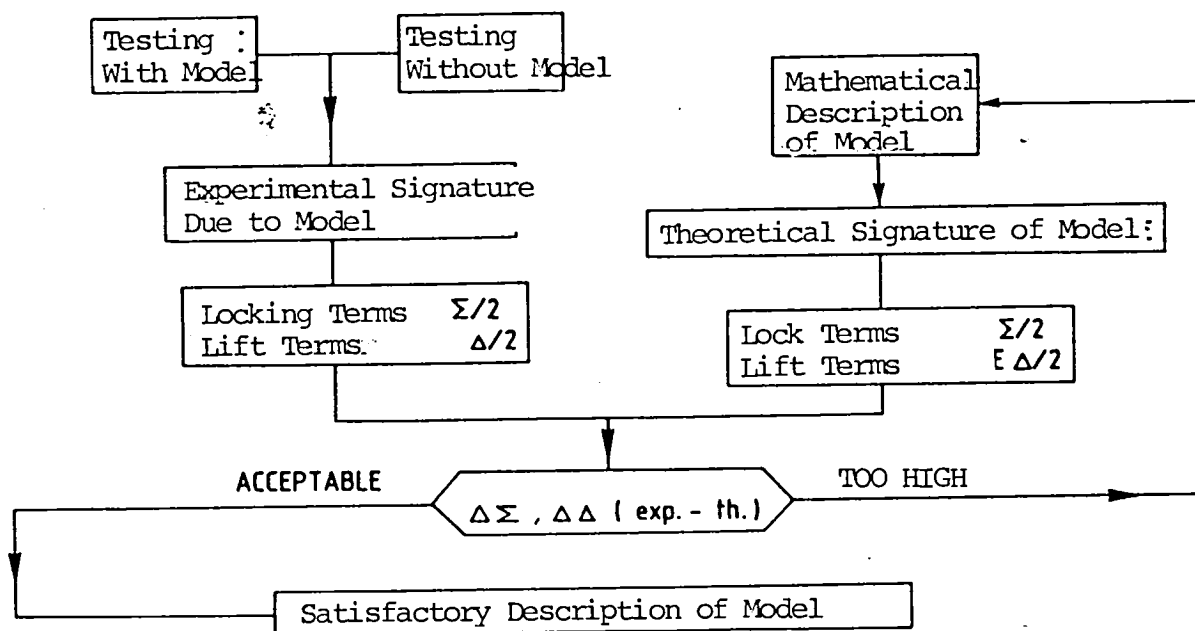


Fig. 7 - Description of Model in Test Section

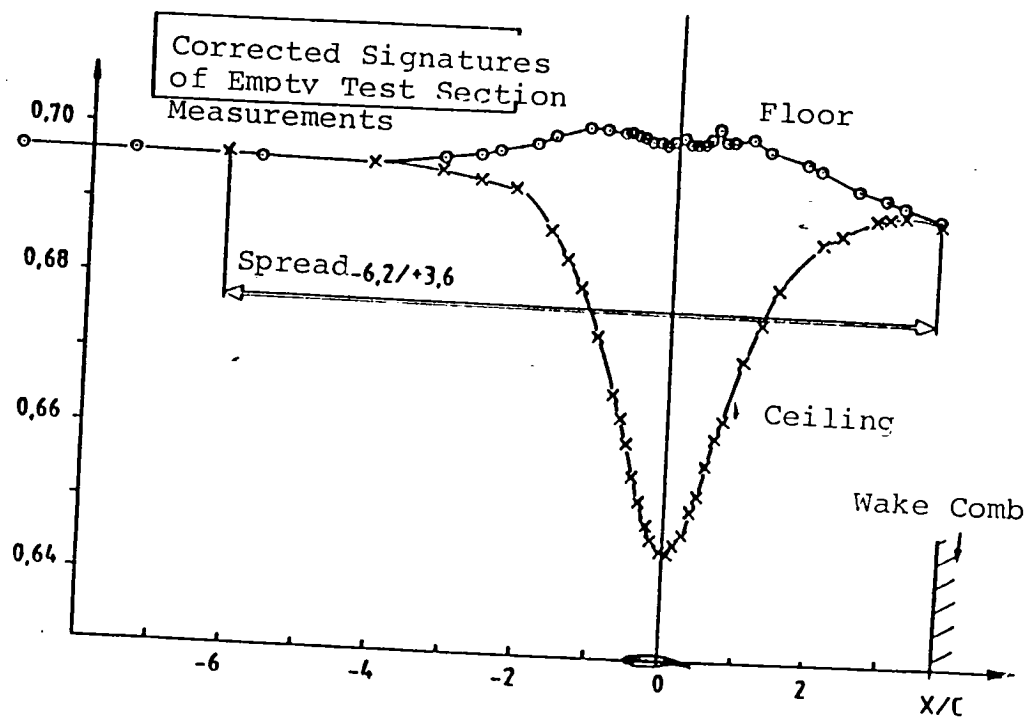
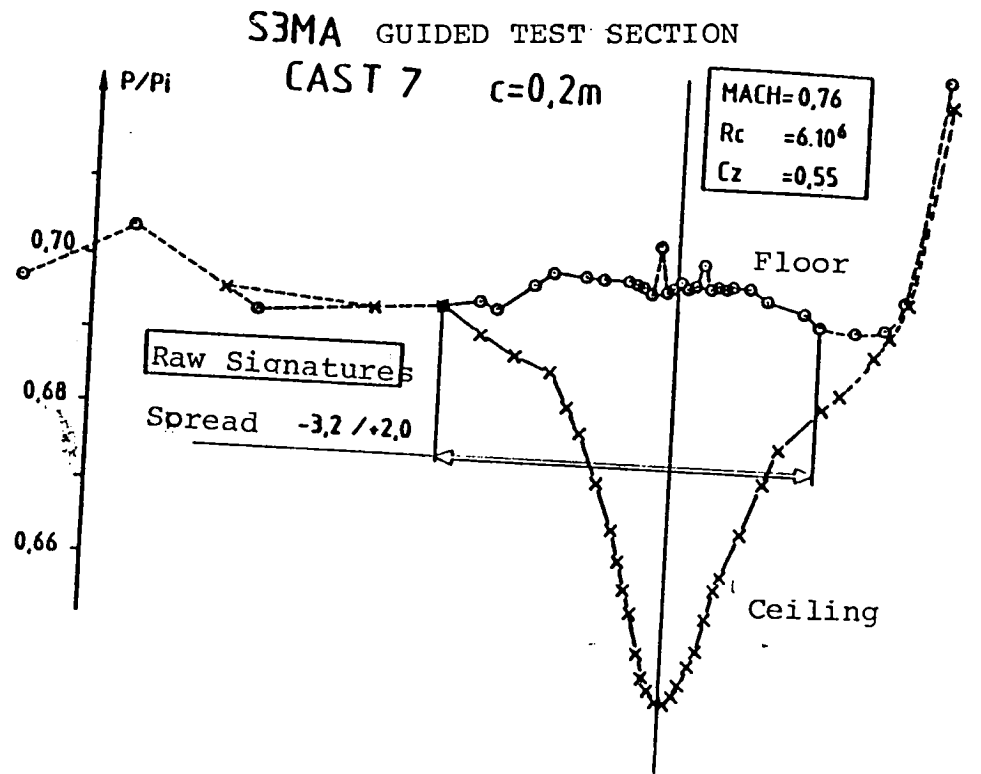


Fig. 8 - 2D - Rough and Corrected Signatures of Empty Test Section

S3MA GUIDED TEST
CAST 7 SECTION

$c = 0,2 \text{ m}$
 $M = 0,76$
 $Rc = 6.10^6$

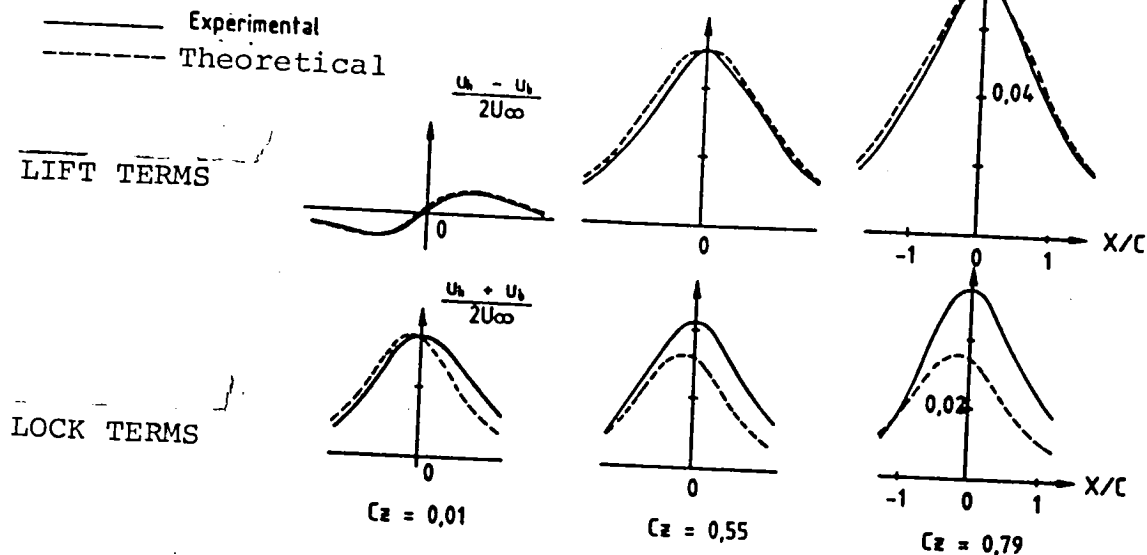


Fig. 9 - 2D Comparison of Calculated and Measured Signatures

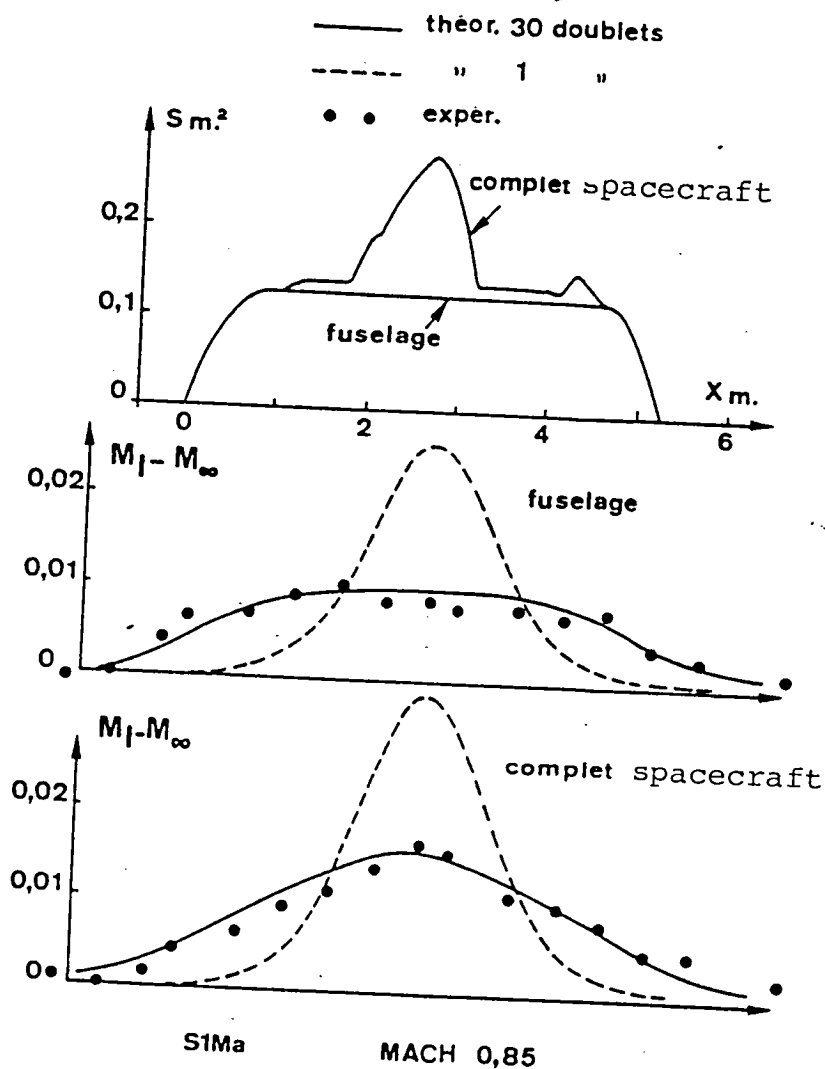


Fig. 10 - 3D Signatures on Solid Walls

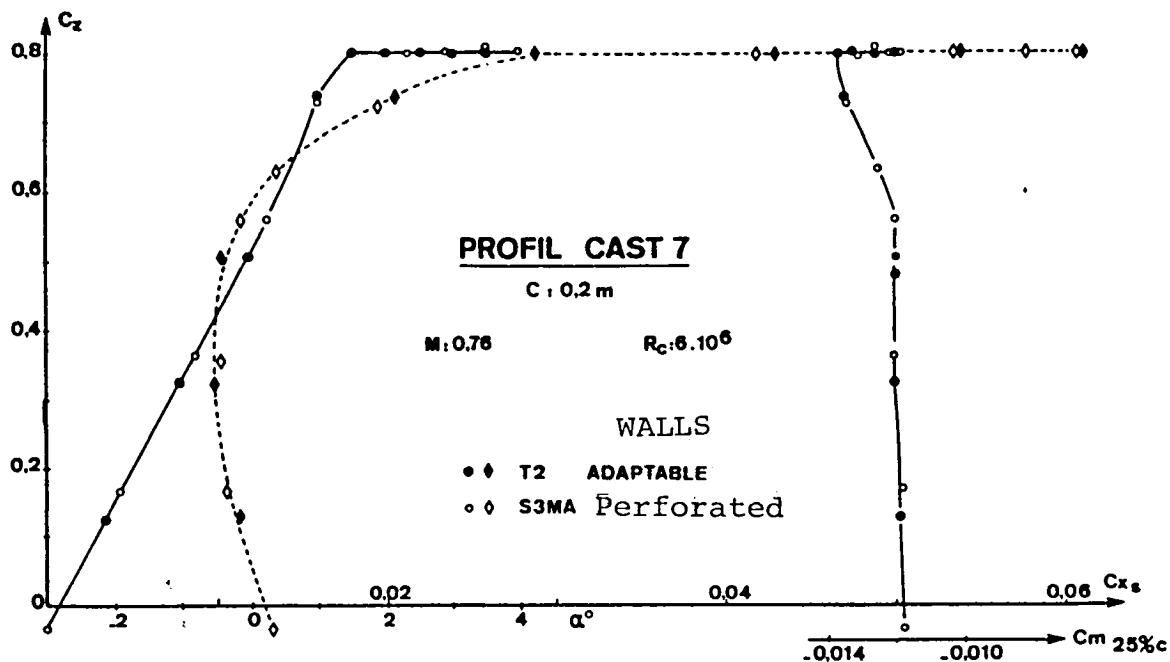


Fig. 11 - CAST 7 Profile - Comparison S3MA-T2 Results

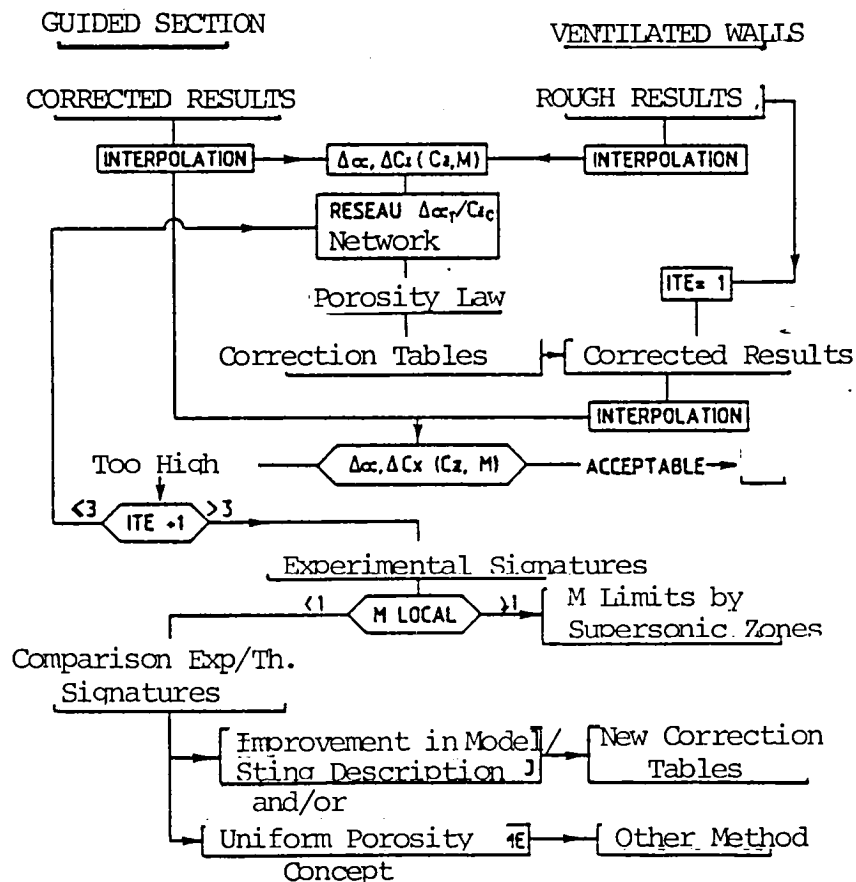


Fig. 12 - Determination of the Porosity Laws of a Test Section With Ventiladed Walls.

$$M_{\text{maxi}} / \text{Walls} = 0.1$$

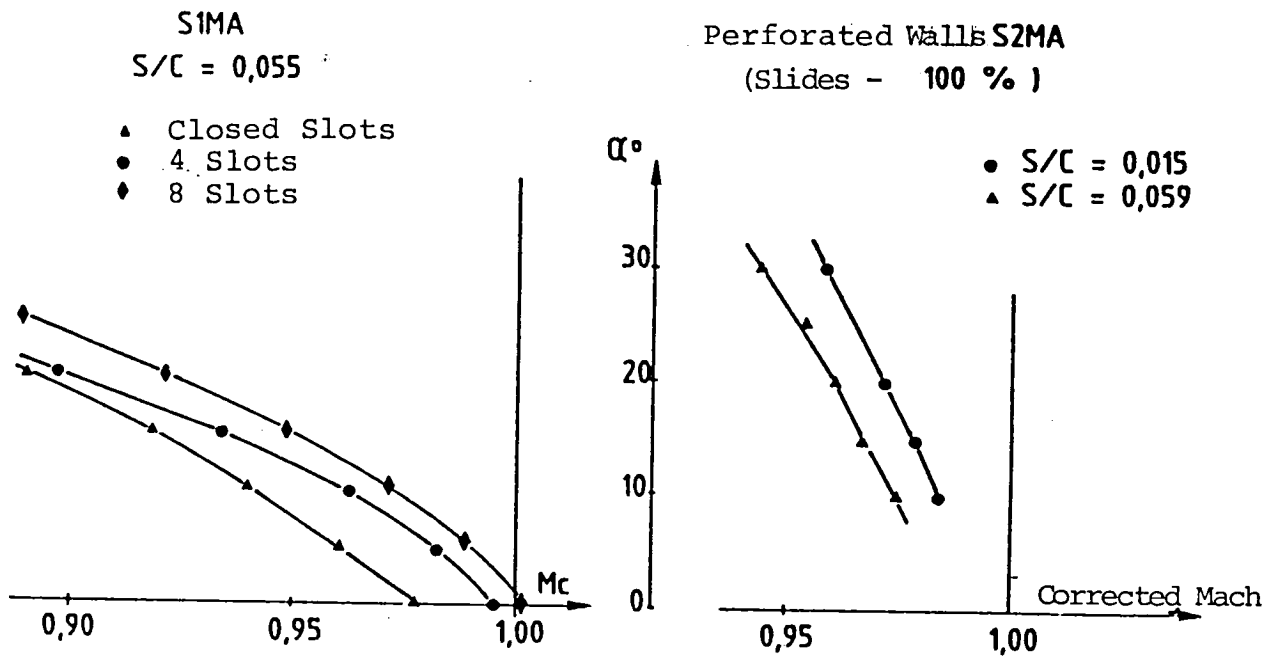


Fig. 13 - Limitations Due to Supersonic Field

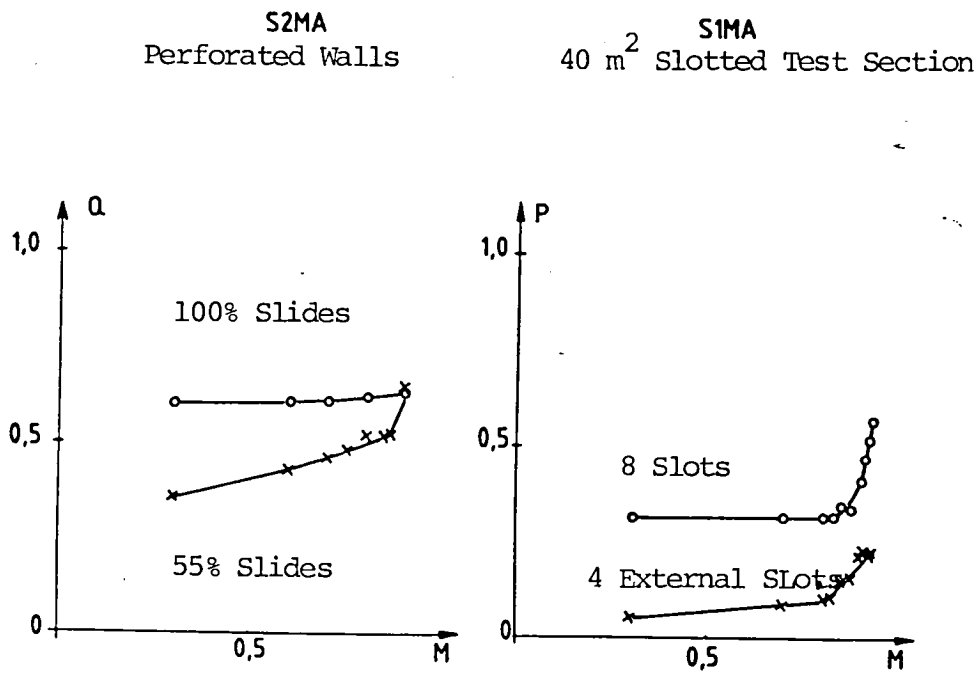


Fig. 14 - S1Ma, S2MA Porosity Laws

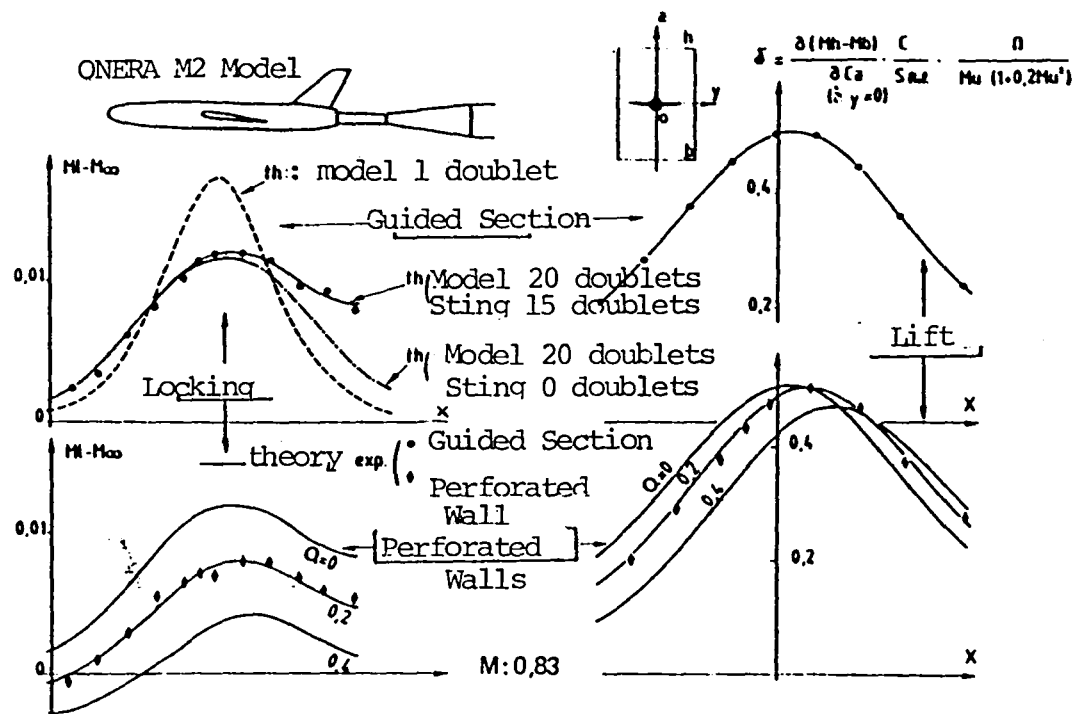


Fig. - Signatures on Perforated and Solid Walls - S3MA

S5 CEAT
 CIRCULAR GUIDED SECTION
 STING HOLDER + STING
 AMD-BA

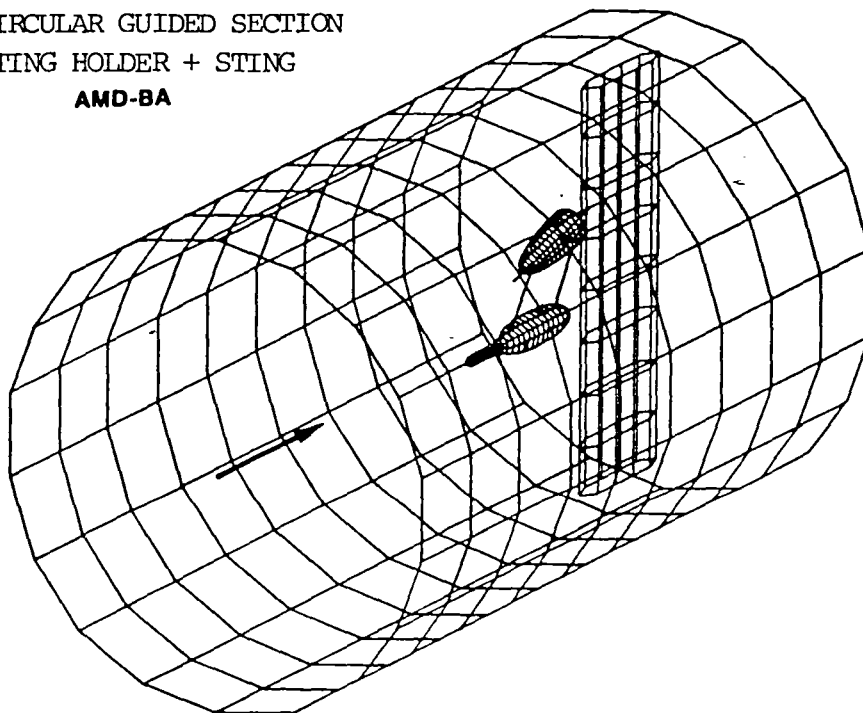
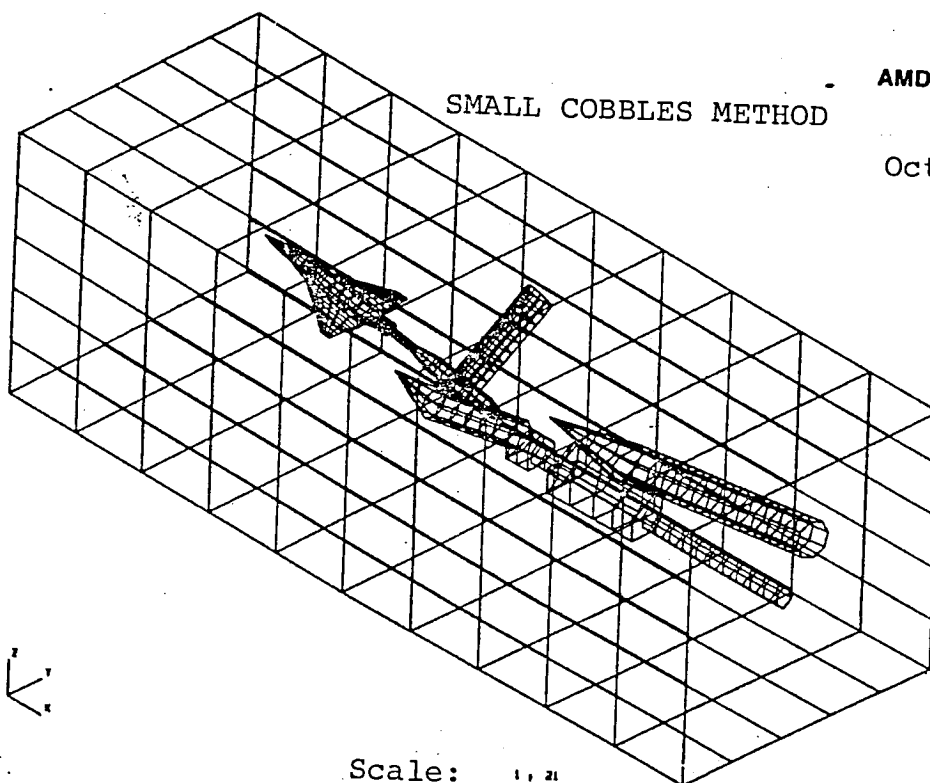


Fig. 16 - Sting Interference in Guided S5 CEAT Test Section



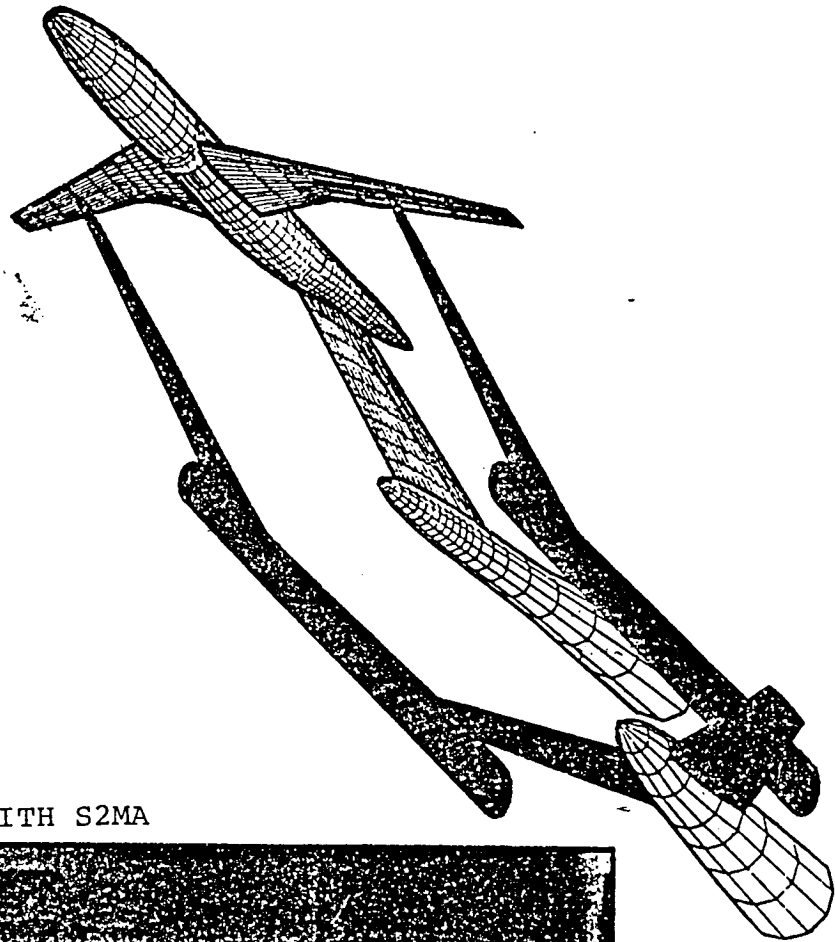
SMALL COBBLES METHOD

AMD-BA

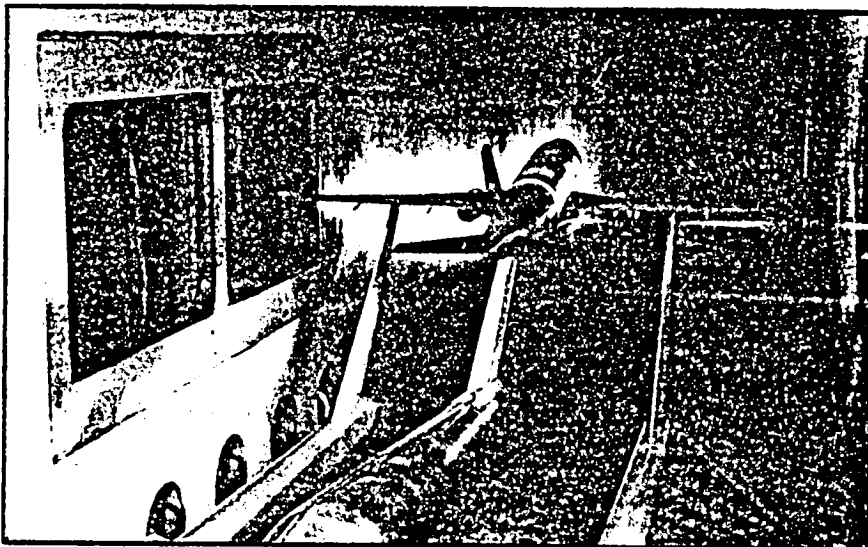
October 1983

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Fig. 17 - Support Interference in S2MA Guided Test Section



ASSEMBLY WITH S2MA



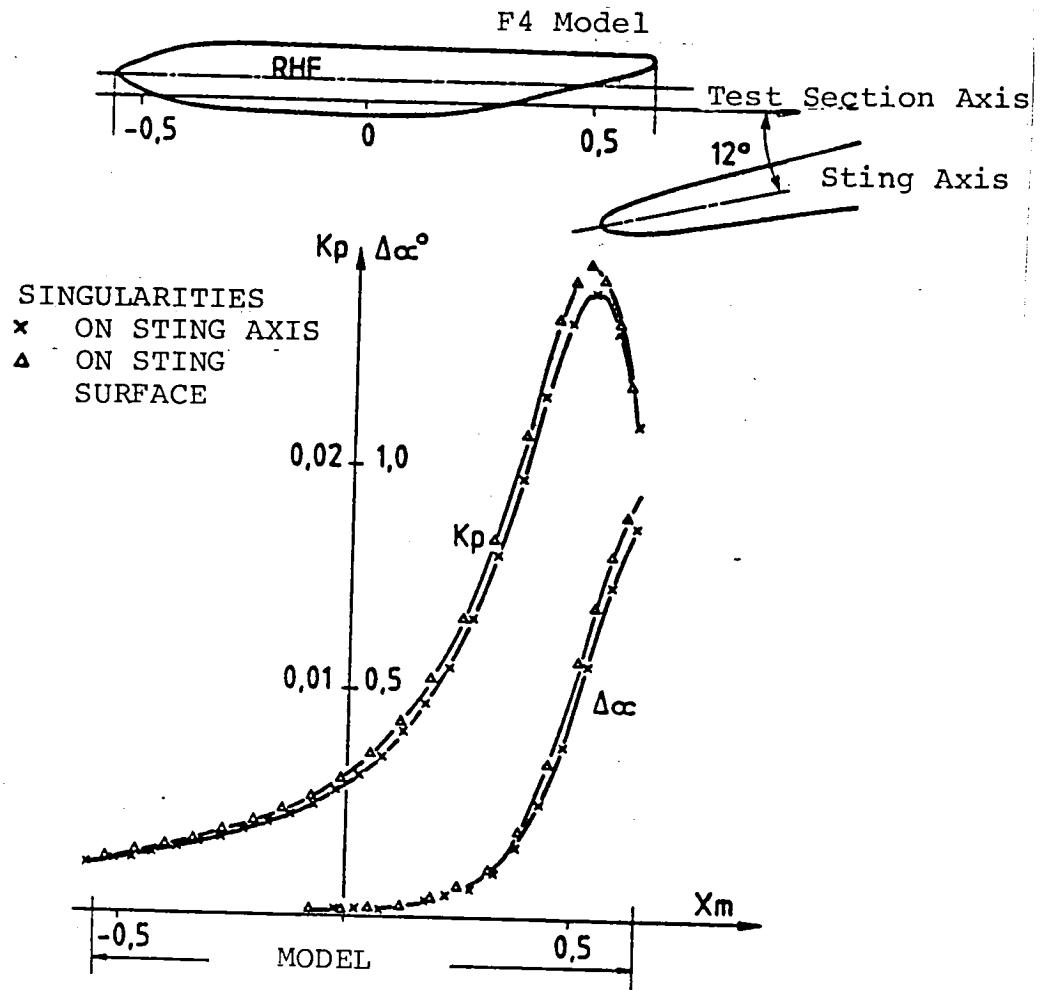
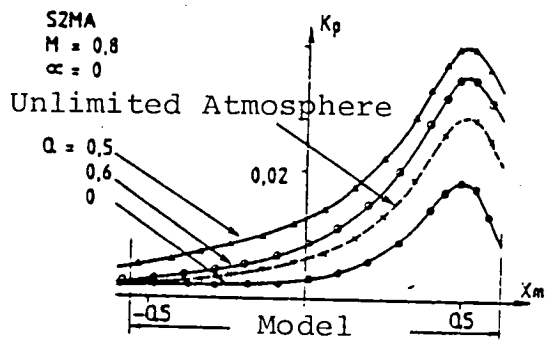


Fig. 19 - Sting Interference. Calculations in Unlimited Atmosphere.



WALL IMPACT ON STING INTERFERENCE

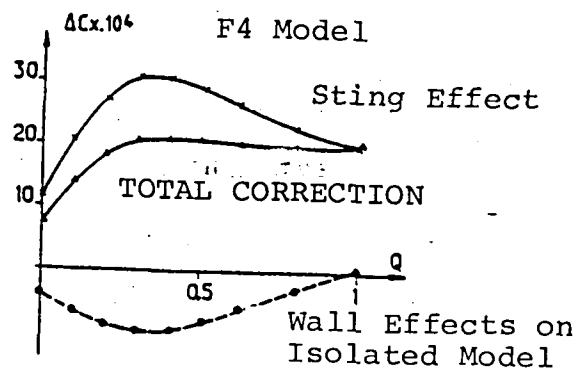
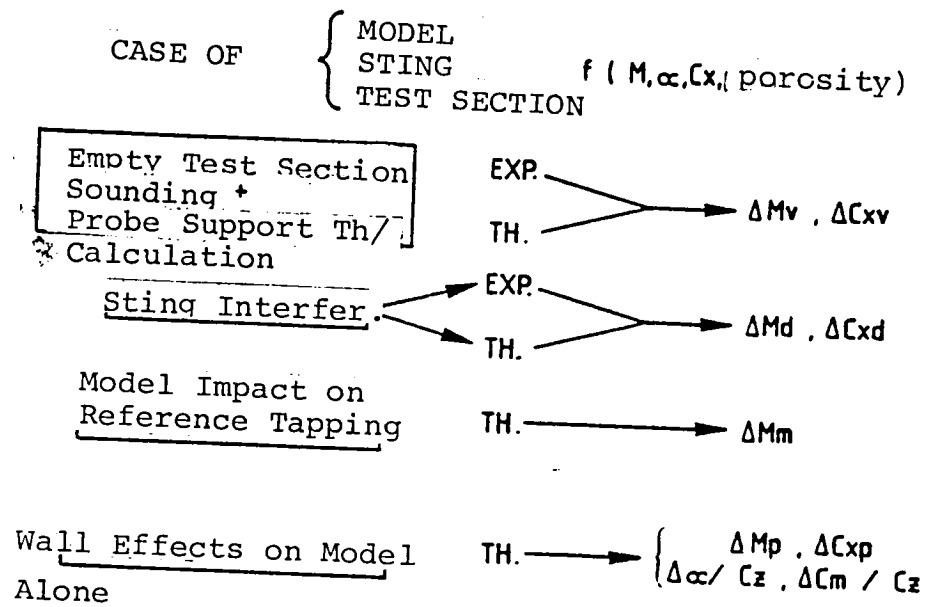


Fig. 20 - Wall Effects on Sting Interference



RESULTS/CORRECTION TABLES

Chart $\frac{\Delta \alpha_r}{C_{z_c}} = f(M, \alpha, C_x, \text{porosity})$

or $\frac{\Delta \alpha_r}{C_{z_c}} = \underbrace{\frac{q_c}{q_u} \left(\frac{\Delta \alpha}{C_z} \right)}_{\text{Lift}} + \underbrace{\left(\frac{q_c}{q_u} - 1 \right)}_{\text{Lock}} \frac{1}{C_{z_\alpha}}$

c = Corrected
u = Not Corrected

Fig. 21 - Preliminary Corrections Calculations

N-156157

N86-28097#

NASA TECHNICAL MEMORANDUM

NASA TM-88447

WALL EFFECTS IN WIND TUNNELS

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N86-28097*# National Aeronautics and Space Administration,
Washington, D.C.

WALL EFFECTS IN WIND TUNNELS

J. P. Chevallier and X. Vaucheret Jul. 1986 40 p Transl. into
ENGLISH of conference paper "Effets de Parois en Soufflerie"
rept. ONERA TP-1983-143 ONERA, Toulouse, France, presented
at the 20th Colloquium on Applied Aerodynamics of the AAAF.
1983 p 1-31 Colloquium held in Toulouse, France, 8-10 Nov.
1983 Transl. by Kanner (Leo) Associates, Redwood City, Calif.
(Contract NASw-4005)

(NASA-TM-88447; NAS 1.15:88447) Avail: NTIS
HC A03/MF A01 CSCL 14B

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the lateral walls is obtained at T2; (2) for the three-dimensional
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O.N.E.R.A.,
Colloquium on
ice, November

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STANDARD TITLE PAGE

1. Report No. NASA TM 88447	2. Government Accession No. N86-28097	3. Recipient's Catalog No.
4. Title and Subtitle WALL EFFECTS IN WIND TUNNELS	5. Report Date July 1986	6. Performing Organisation Code
7. Author(s) J.P. Chevallier, and X. Vaucheret	8. Performing Organisation Report No.	10. Work Unit No.
9. Performing Organization Name and Address Leo Kanner Associates Redwood City, CA 94063	11. Contract or Grant No. NASW-4005	12. Type of Report and Period Covered Translation
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration, Washington D.C. 20546	14. Sponsoring Agency Code	
13. Supplementary Notes Translation of "Effects de parois en soufflerie, O.N.E.R.A., Report No. T.P. 1983-143, presented at the 20th Colloquium on Applied Aerodynamics of the AAAF, Toulouse, France, November 8-10, 1983, pp. 1-31		
16. Abstract A synthesis of current trends in the reduction and computation of wall effects is presented. Some of the points discussed include: (1) for the two-dimensional, transonic tests, various control techniques of boundary conditions are used with adap- tive walls offering high precision in determining reference conditions and residual corrections. A reduction in the bound- ary layer effects of the lateral walls is obtained at T2; (2) for the three-dimensional tests, the methods for the reduction of wall effects are still seldom applied due to a lesser need and to their complexity: (3) the supports holding the model of the probes have to be taken into account in the estimation of perturbatory effects. <i>interference</i>		
17. Key Words (Selected by Author(s))	18. Distribution Statement Unclassified-Unlimited	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 22.

A84-19932#
(ORIGINAL)

WALL EFFECTS IN WIND TUNNELS

by J.P. Chevallier and X. Vaucheret

INTRODUCTION

/3*

The recent first commercial operation of the NRF high Reynolds number wind tunnel (NASA Langley) [1] , the European ETW wind tunnel project [2] and the continuous request of manufacturers for more specific test conditions in existing installations have led to the creation of different work groups to study the problem of wall effects from the three-fold standpoint of their determination, their reduction and their correction. We may mention in particular an AGARD work group under the auspices of the "Wind Tunnel Testing Subcommittee of the Fluid Dynamics Panel" [3], and the GARTEUR action groups [4]. The most important results were also presented during the following meetings:

-AGARD-FDP Meeting at London on May 19, 20, 1982 (17 reports on wall effects in wind tunnels) [5];

-AGARD FMP Meeting at Smyrne on October 11 to 15, 1982 [6];

-Working sessions on "the reduction and correction of wind tunnel wall effects" NASA Langley Research Center January 25-26 1983 [7].

-53rd AGARD FDP Meeting on "Wind Tunnels and Testing Techniques" at Cesme on September 26 to 29, 1983 where 36 reports were presented, particularly that of Bignon and Kraft [8], presenting the conclusions of the 1982 meeting at London [5].

Of all studies presented, our purpose is to reveal which of these are current trends and to specify our own practices. To accomplish this, we shall first examine the means currently used to reduce wall effects, then recent methods of calculating these effects, because the two problems are now intricately interrelated.

It seems that there is a quasi general agreement on the need to use measurements of the ^{velocity} speed field in the vicinity of the walls to calculate interferences. Measurements of the same type will be used for testing the boundary conditions when we try to minimize these interferences.

In the second part the methods are applied to industrial wind tunnels based on ^{partial} parietal ^{boundary} measurements so as to test the representation of the model and its support.

1 - VARIOUS METHODS FOR REDUCING OR CALCULATING WALL EFFECTS

1.1 - REDUCING WALL EFFECTS

^{This reduction in wall effects}
~~It~~ is generally achieved ^{using} because the term "adaptive walls" ~~is used~~. ^{This} It is a vague term covering highly diverse practices using for example:

- permeable walls (perforated walls with variable porosity, ^{segmented} fractionated suction chambers, controlled back-pressure; changing slits with valves or counterplates; transversal ^Cflaps),

- flexible solid walls.

/4

Various devices for measuring the ^{velocity} speed field are combined with these means of testing the transversal ^Cflow component: isolated probes, longitudinal tubes fitted with pressure taps, laser velocimetry, ^{partial} parietal ^{wall} taps. We will limit ourselves to a brief description of operational systems, the results of which are published and to the most advanced projects, primarily for two-dimensional testing. The characteristics reduced in terms of test section height (table 1) ^{allow} facilitate ^{comparisons} comparisons.

-Wind Tunels With Perforated Walls and Multiple Chambers

The first developed at CALSPAN based on Sears' ideas [9] has a section 25 cm wide and 30 cm high, walls with normal perforations (22.5% opening) with 8 lower chambers and 10 upper chambers, tested individually. Measurements of the flow speed and direction on the control surface, performed at the beginning with clinometric probes now are due to the calibration of longitudinal tubes equipped with 2 rows of pressure taps arranged ^{perpendicular to one another} over opposite generators. These tubes, installed over a rotary support, should enable measurements to be performed on a cylindrical control surface for the extension of three-dimensional flows (Wind tunnels 1T, then 4T of AEDC) figure 1.

-Wind Tunnel With Slits and Multiple Chambers

At the ^{NASA Amco} ~~center of~~ AMES [10], a 25 x 13 cm² wind tunnel has 6 suction compartments for each wall. These compartments are in turn divided ^{spanwise} ~~widthwise~~ into 3 chambers for a three-dimensional adaptation. The measurement of 2 disturbance speed components on one control surface is replaced by the use of 2 control surfaces with measurement of the one cross-component using a laser velocimeter.

-2D Wind Tunnels With Solid Flexible Walls

At the Univeristy of Southampton, the TSWT (Transonic Self Streamlining Wind Tunnel) has a 15 x 15 cm² square section and a very long test section (1.12 m) whose upper and lower walls are each shaped using 20 electric actuators with a similar number of ^{wall} parietal pressure taps [11]. As such the wind tunnel was used for two- and three-dimensional testing to determine whether the disturbances ~~to be~~ measured on the walls of these are difficult to obtain with precision (figure 1).

At the Technical University of Berlin [12], the T.U.B. wind

tunnel has a $15 \times 15 \text{ cm}^2$ square section with two flexible walls over 0.69 m each shaped by 8 direct current actuators with a 25 mm path and equipped with some 20 pressure taps.

5 bars
run
mm
At CERT at Toulouse, the T2 wind tunnel [18], which was the subject of 2 reports [13, 14] has over its competitors the advantages of one order of magnitude at least with respect to the Reynolds numbers ($0.37 \times 0.38 \text{ m}^2$ test section and generating pressure 5b) and an excellent relative precision in the knowledge of wall shapes (using potentiometers of about 0.05 mm) ^{accuracy} and ^{velocity} speed distributions (with 91 pressure taps on each wall). By ^{minimizing} vectorizing the program for calculating the virtual field and optimizing the relaxation factors reducing the time required for adaptation during a ^{tunnel} gust of a few tens of seconds.

In addition to these advantages, the T2 wind tunnel has a relatively short test section (table 1). What can we conclude about the precision of the reference conditions obtained in these conditions? We shall return to this essential point after a brief review of the new methods of assessing wall effects. It should be pointed out that an attempt has been made to compensate for lateral boundary layer effects using reliefs made by gluing paper cut out in the shape of ^{stream} level lines [15]. This procedure finds its justification in recent CEAT tests [16] which show the existence at the root of the model ^{of} two small counter-rotative ^{ing} vortices, very different from the ^{representation} modelization proposed by Preston [17].

3D Wind Tunnels With Flexible Walls

^{at} AFFDL
At the ~~NASA center~~ of Wright Field, a $9'' \times 9''$ test section (i.e. about $23 \times 23 \text{ cm}$) ^(figure 5) is operating ^{which} under 4b, has 2 flat side walls whereas the other two are made up of flexible rods with alternating circular and triangular sections activated by some 100 actuators. No measurements ^{were} was performed on the ^{side} walls [3].

At the Technical University of Berlin [12] a second test section, with an $18 \times 15 \text{ cm}^2$ octagonal section, is used for 3D tests. The feasibility of such tests was ^{described} demonstrated recently in an operation ^{presentation} at Cesme in September 1983 (figure 3), despite the small ^{wall} deformations ^{required} to be achieved (of the order of one mm).

At DFVLR, in the advanced project, Dehnbare Adapative Meb- ^{rubber} strecke (DAM) the circular test section was made up of an elastic ^{rubber} tube 800 mm thick whose diameter was stretched into 8 ^{directions by} sections by 64 ⁴ 8 actuators [12] (figure 3).

1.2 - NEW METHODS OF CORRECTING WALL EFFECTS

This was the title, in singular form, of a report presented at the 14th Symposium of Applied Aerodynamics at Toulouse in 1977 [19]. We still use this name for methods which have multiplied for 6 years and whose common points is to call on measurements ^{of the wall boundaries} made on walls, or in their vicinity. Created from the necessity of being applicable to adaptive ^{cell} but not perfectly adapted walls, this ~~type of~~ method has for conventional walls the advantage of eliminating certain controversial assumptions on lineary boundary conditions [18, 20].

Without going into too much detail, we may mention the following methods in the order they appeared:

Kemp: the unknown intensity ^{ies} of the singularities arranged at the walls and at the location of the model ^{are} is determined to ^{from} satisfy with ^{velocity} speed measurements ^{at} on an equal number of control points, on the model and at the walls, by resolving the linear system formed with the corresponding impact factors. The ^{boundary} parietal singularities thus defined contribute alone to the interferences under investigation.

-Smith [25]: the NLR I method differs from that of Kemp only

in the limitation of the unknown singularities at the wall, the model being represented by given singularities, functions of its geometry and of overall lift and drag measurements.

This Capalier et alii^e [19]: In contrast to the two aforementioned methods, ^{this} the formulation^s expressed^d in terms of integrals of the ^{velocity} speed deviations measured at the walls and calculated for the model. This avoids resolving the linear system and therefore eliminates the consequences of random errors in the measurements. This method applies not only to the two-dimensional case, but also to three-dimensional flows in test sections with a rectangular section and flat side walls.

^a Swada [22] presented a very similar method which he recently applied to two-dimensional unsteady flows [37].

Mokry and Ohman [23]: Dirichlet's problem ^{of determining} for^a the axial speed ^{velocity} inside the surface upon which boundary data are collected is solved in the form of a Fourier-Bessel series for three-dimensional cases. Their coefficients are obtained using rapid Fourier transforms.

For corrections calculated on the axis of the test section, a cylindrical control surface may be used no matter what the shape of the test section has.

Mokry compared these methods [24] ^{for} on a two-dimensional test case and showed that [19] and [23] gave identical results and [22] and [25] deviated only very slightly.

Ashill [27] as well as Smith in the unpublished NLR II method avoiding the use of the model which may be delicate in the presence of supersonic or separation regions in the flow. They should therefore use measurements of the two disturbance components in the vicinity of the walls.

Mach=1

All of these methods are of the linear type and are limited for this reason below $Ma=1$. Also they implicitly assume that the boundary conditions are homogeneous enough for the measurements near the walls to be significant.

For any method used, the precision required in knowing the two disturbance components will be brought to light through the explicit formulation of the ^{velocity} speed and incidence corrections, based on the relative longitudinal disturbance component u [19] cu , according to the so-called conjugated formulation [28], on the relative transversal component v . By letting u_i and v_i be the wall interference components at the center of the test section and by simplifying the formulas given in [18] based on an empty test section.

$$\begin{aligned}
 (1) \quad u_i(x,0) &= \frac{1}{\beta h} \int_{-\infty}^{\infty} \frac{u(\xi, h/2) + u(\xi, -h/2)}{2 \operatorname{Ch} \pi(\xi-x)/\beta h} d\xi \\
 (2) \quad v_i(x,0) &= \frac{1}{h} \int_{-\infty}^{\infty} \frac{u(\xi, h/2) - u(\xi, -h/2)}{e^{2\pi(\xi-x)/\beta h} + 1} d\xi + C \\
 (3) \quad u_i(x,0) &= \frac{1}{h} \int_{-\infty}^{\infty} \frac{v(\xi, h/2) - v(\xi, -h/2)}{e^{2\pi(\xi-x)/\beta h} + 1} d\xi + C \\
 (4) \quad v_i(x,0) &= \frac{1}{\beta h} \int_{-\infty}^{\infty} \frac{v(\xi, h/2) + v(\xi, -h/2)}{2 \operatorname{Ch} \pi(\xi-x)/\beta h} d\xi
 \end{aligned}$$

No problem is raised by using formula (1) because it was shown that it tolerates the truncation of the integration, ~~termin-~~ ^{als} owing to the rapid decrease in the impact function and the fact that it eliminates the reference errors. The same is true for formula (4) in regard to incidence. Conversely, for formula (2) it is necessary to determine the constant C . It is zero if we adopt as reference a flow direction which is sufficiently upstream so that the difference $u(\xi, h/2) - u(\xi, -h/2)$ is zero. It also shows in the nucleus of the integral a speed difference which is delicate to measure.

velocity -

Based on these formulas we therefore conclude that to apply the so-called new correction methods it is necessary to know, at a right angle with the model, the speed vector in modulus and direction, in the vicinity of the walls, with a precision of the same order of as that required ^{for} on so-called "upstream infinity" conditions.

1.3 - DETERMINING THE REFERENCE CONDITIONS

The crucial importance of determining these conditions accurately was recently recalled in a report under the "Wind Tunnel Testing Techniques" Committee of AGARD-FDP which set forth the requirements of airplane manufacturers with respect to wind tunnels [29].

The investigation of an error limited to $\Delta C_x = 0.0001$ leads to $\Delta M = 0.001$ and $\Delta \alpha = 0.01^\circ$ in regard to the Mach number and the incidence. This goal, which seems a challenge, actually deserves considerable effort because in other sources [30] it is shown that a 1% gain in the cruise drag (considerable ~~only~~ in these conditions) is profitable even if we have to ^{quintuple} ~~quadruple~~ the number of aerodynamic tests of a transport aircraft.

How can we possibly know the direction and speed of an "infinite upstream" flow in a wind tunnel with such accuracy?

Excluding the support effects, which will be discussed in the second part, and remembering that we have to know the direction and speed on a control surface with the same precision, by examining the errors inherent to the various procedures for measuring the flow disturbance components (laser, clinometric probes, etc), here at ONERA we think that there is only one valid procedure: using deformable solid walls where the quality of the surface condition and pressure taps is equal to that obtained on airfoils and position measurements showing the shape of the wall (which will be

corrected for the boundary layer displacement thicknesses).

Among the wind tunnels which try to achieve these conditions, we see that T2 has a shorter test section, but that it is long enough to define the reference conditions perfectly, given the balance functions discussed above. It has the largest number of ^{boundary} parietal pressure measurements and actuators near the model and the best definition of the wall positions. The ^{range} scope of the ^{wall} displacements is slightly smaller and as a result the dimension of the model is limited. The ^{wall jack} ~~displacement~~ ^{wall jack} pitch in other regions is too strong.

^{under discussion} In these apparently optimal conditions, has the objective focussed on been achieved? It is virtually impossible to calculate an error: the shapes of adaptive walls are derived by processing an external virtual flow using Green's formula and whose ^{wall} parietal ^{velocity} speed measurements are the data. Conversely, the ^{flow} ~~over~~ ^{accelerations normal to} speeds at a right angle with the model are also functionals of /8 the slopes obtained by smoothing and interpolation of the measured dimensions. An intrinsic validation was therefore tried by placing the same ^{model} model (CAST 7 airfoil with a 200 mm chord) ^{on} over the axis of the wind tunnel and at 80 mm below this axis. By adapting ^{wall} for each case, the wall shapes and parietal pressure distributions are totally different [15]. The variation of the lift factor as a function of the Mach number for angles of 0 and 1°, shown in figure 6 on a large scale, shows the ^{scatter in} ~~dispersion of~~ the measuring ^{data} ~~points~~. The latter does not show any systematic deviation due to the difference in testing conditions and it seems small enough for us to be able to conclude that the objective is virtually if not fully achieved. This success in two-dimensional testing leaves promising prospects for extensions to three-dimensional flows provided that all precautions are taken to observe the purity of the flows, the homogeneity of the boundary conditions and the precision of the ^{boundary} ~~parietal~~ measurements in the presence of considerably smaller disturbance fields.

2 - WALL AND SUPPORT EFFECTS IN ONERA'S INDUSTRIAL WIND TUNNELS

In wind tunnels not yet equipped with adaptive walls and with magnetic suspensions, it is still necessary to make corrections for wall and support effects to restore as far as possible the results which would be obtained on models in an unlimited atmosphere. There are two types of corrections to be made for the potentials under consideration:

- the wall effects are calculated based on the interference potential promoted by the walls,
generated

- the support effects are the result of the sum of the potential of the supports in an unlimited atmosphere and of the interference potential promoted by the walls.
generated

2.1 WALL EFFECTS

Two methods are currently employed for calculating wall effects. These methods have already been presented.

The first method, called the "conventional method" [31] consists of calculating the potential promoted by the walls by solving a problem whose data are the following: *data:*
which requires the

- the potential of the model in an unlimited atmosphere,
unconfined flow
unconfined flow
- the boundary conditions on the walls of the test section involving the concept of 'equivalent uniform wall porosity'.

The second method, called the "signature method" [19] allows the potential promoted by the walls to be derived from data consisting of: *generated*

- the potential of the model in an unlimited atmosphere,
unconfined flow

-the distributions of pressures measured on the control surfaces of the test section (signatures).

These two methods have in common the assumption of a cylindrical test section ^{extending} reaching to infinity, and the necessity of making use of a mathematical description of the model. /9

2.1.1 Mathematical Description of the Model

Since we are referring to a corrective calculation and not a calculation of the flow ^{on} the model, the specification of the model is rudimentary: it should include the required number of singularities for the model field to be properly represented at a distance from the model. The best way to control the specification consists of comparing the signatures measured and calculated on the walls of the test section in a configuration with perfectly known boundary conditions: in this case the use of solid walls is unambiguous.

The iterative process (figure 7) is ^{associated} as the following: ^S using signature measurements on the walls of a ^{solid} ^{walled} guided test section, in the presence and in the absence of a model, by adding and subtracting we find the ^{components associated with blockage} ~~parts for the locking~~ and lift terms corresponding to an isolated model. The model specification associated with zero porosity conditions of the walls makes it possible to obtain signatures at the same locations of the test section and to divide them into ^{blockage} ~~locking~~ and lift terms. An examination of the differences between calculated and measured signatures makes it possible to check whether the model specification should be improved and in this case which part of the specification, volume, wake, lift is to be altered to be acceptable in terms of manufacturer specifications.

Two examples illustrate the mathematical specifications of the model.

uniform
inform

The first example concerns tests on a profile in a flat ^{stream} ~~current~~ in S3MA in a ^{closed} ~~guided~~-test section configuration. An example of the signatures measured in the presence of a profile, then corrected of ^{the} ~~the~~ readings in the absence of a profile (figure 8), show that the tapping errors were eliminated as well as the effect of the wake comb located downstream. A comparison of the calculated and measured signatures (figure 9) show that the lift ^{distribution} ~~description~~ due to two intensity vortices derived from measurements of C_z and C_M is adequate [32]. At zero lift, the description of the volume using a single doublets is also adequate. Conversely, the description of the wake using a single source is increasingly incorrect when Z_z (therefore C_v) increases. This is due to the ^{model} ~~absence of the tapping by considering the~~ separations in the ~~des~~-cription. Work is now underway to correct this.

The second example concerns a space model (figure 10) in a 47 m² SIMA test section. The description of the streamlined bodies is here a ^{number of} ~~double~~ doublets, ^{based on} ~~number of~~ the ratio between the length and diameter of the body. We see that the calculated signatures ~~are~~ in good agreement with the measurements, ^{representing} ~~personalize~~ well the shape of the model: ^{the} ~~flat~~ signature for the fuselage alone, ^{and a more} ~~bulging~~ shape for the entire spacecraft.

When the mathematical description of the model is considered to be correct, calculations may begin to correct the wall effects.

2.1.2 Signatures Method

/10

As indicated above, this method does not require knowledge of wall porosities. One simply needs to measure the signatures over a control surface so that the wall porosity effects are homogeneous.

^{With} In perforated walls, and ^{walls} ~~a fortiori~~ solid ones, these control surfaces are the walls themselves. The ^{extent} ~~duration~~ of the signature measurements does not exceed that of the wake measurements of a

^{streamlined}
flat current profile. This method is systematically applied to profile testing in S3MA. The corrected results obtained on the CAST 7 profile are in good agreement with those obtained in the test section with adaptive walls of the T2 wind tunnel of CERT/TOULOUSE (figure 11). ~~as well as for the lift curves and for the stability curves of the maximum C_z .~~

In the case of walls with ⁰slits, the signatures may no longer be sampled on the walls. According to a recent publication [20], the signatures should be recorded at a distance from the walls which is virtually equal to the ⁰slit pitch. This is a problem for the test section which has a limited number of ⁰slits.

2.1.3 ^{Classical} Conventional Method ^{has}

In addition to a correction description of the model, it is necessary in the ^{classical} conventional method to know the wall porosity laws as a function of the Mach ^{number} and of the ^{driving} generating pressures and to validate the concept of uniform wall porosity.

The reference tests [31] ^{were made} are referred to determine the wall porosity laws. These tests may be ^{carried out} obtained by performing tests on the same model, ^{at} with the same Reynolds number:

-in the same test section rendered ^{closed} guided by ^a the ventilation mask,

-in a ^{test} ~~test~~ section with such dimensions that the wall effects are negligible.

As far as possible the second type of reference ^{choking} is preferred because it has no limits due to the test section ^{choking} locking and does not require corrections which are high in three-dimensional cases.

The iterative process used for defining the porosity laws is the following (figure 12).

The work always includes an interpolation in M , C_z of the wind tunnel data. The first assessment of the deviations to be reabsorbed by corrections is established in incidence deviations as a function of C_z at a fixed Mach, and in C_x deviations as a function of M for a given C_z .

The deviations of M and C_z between interpolated results, corrected for the reference test and not corrected for the ventilated wall test are introduced into the curve networks established as a function of porosity. This gives the first porosity law. It is used to correct the results of the ventilated wall test. The differences between the interpolated results corrected for both tests are then examined. If these differences satisfy the manufacturer's precision specifications, the work is completed. Otherwise, the process is repeated. In general, three iterations are necessary. If differences still exist, the reasons are investigated. /11

An examination of the pressure distributions measured on the walls of the test section make it possible to define the Mach-incidence limits beyond which the Mach number is greater than 1. In fact, this value is obtained on the ceiling ^{when} there is not yet ^{complete choking} any locking of the test section: the supersonic region on the top surface skin of the wings reaches the ceiling. The wall corrections are then no longer applicable. Figure 13 shows, for a corrected Mach ^{number}, the limits obtained at SIMA for three ^{slot} conditions and at S2MA for 2 homothetic models.
similar

In the case of an S2MA transonic test section, for two used conditions of ^{the} perforated walls ^{ie.} (by opening slide valves by 100 and 55% to modify the porosity), the porosity laws (figure 14) were established by using as reference tests, tests on the same model in SIMA with an area 13 times larger than that of S2MA. These laws proved to be correct for full and half civilian aircraft models up to Mach 0.92 and for full military aircraft models up to the limits due to supersonic zones.

The growth of the

In the case of a 20 m^2 SIMA test section, the porosity laws (figure 14) of 4-slotted or 8-slotted open configurations were defined in the reference for tests performed in closed slotted configuration. These laws are correct up to Mach 0.85.

Beyond this value, there are still differences between the corrected results, obtained for the three test section cases, and an attempt is being made to resolve these differences.

2.1.4 Indirect Signatures Method

One variant of the ^{classical} conventional method consists of basing oneself on the signatures calculation as ^{of the signatures on} a function of the porosity parameter assumed to be uniform and by comparison with the measured signatures to derive the wall porosity cartography. This variant was used for the case of the S3MA perforated wall test section. After verifying the correct description of the ~~locking~~ ^{closed} and lift terms in a ^{closed} guided test section, figure 15 shows that for perforated walls, a comparison of the signatures leads to a Q uniform porosity parameter Q of 0.2 on the walls. This porosity is moreover identical to that derived from the overall efforts in a ^{closed} guided reference test section. ^{blockage}

In fact, this indirect signatures method is used to check the validity of the wall uniform porosity concept.

In test sections with perforated walls, a porosity test by comparing the measured and calculated signatures has not raised any special problems. As with this case, the concept of a uniform equivalent porosity was not handicapped by examining the signatures. The ^{classical} conventional method was retained because it is not penalizing in terms of computer time, after the porosity laws are established. Generally speaking, the more the porosity concept is uniform, the more the mathematical description of models and stings proves to be inadequate. /12

2.2 MODEL SUPPORT INTERFERENCES

Corrections of the Mach number and of the Archimedean^{ian} thrust^{buoyancy} brought about by the presence of model supports may be obtained experimentally based on measurements of the Kp distributions at the location which the model fuselage axis would occupy. A clinometric^{measurement} sounding_α would also make it possible to know the tail unit setting correction due to supports_α interference.

To avoid costly soundings^{measurements}, a calculation may be performed. Two methods are used at present.

The surface singularities method begins with a meshing of obstacles^{between} in the test section of ~~on its~~ walls. This technique is directly derived from techniques used by manufacturers in an unconfined^{flow} limited atmosphere by adding the walls to simulate the contained^{confined} atmosphere of the test sections. Illustrations of the meshing are therefore borrowed from manufacturers. Figure 16 shows [33] the sting and sting holder in the S5 guided test section of CEAT-TOULOUSE used by DASSAULT-BREGUET. Figure 17 shows the meshing of a Mirage model installed on the wall of the S2MA^{closed} guided test section and of the device with 6 degrees of ^{freedom}liberty to study load trajectories: calculations performed by LE BOXEZ of AMD-BA.

Figure 18 is concerned with the assembly of a civilian aircraft twin sting in a guided test section meshed by AEROSPATIALE. More complex cases including ventilated walls and descriptions of test section ends and upstream^{regions} parts₂ with tapered section are under study. This method is still complicated to use and requires powerful computers.

A description of test section obstacles using singularities distributed over their skeletons of various shapes has been tried recently by ONERA [34]. The only data^{required}_α are the coordinates of the assembly skeleton and the area rule.

An attempt is made to validate this method in an ^{unconfined} unlimited ^{flow} atmosphere by comparison with the results of previous more sophisticated methods. Figure 19 shows, in these conditions, a good agreement of the Kps and incidence promoted by an inclined support used in a sabre assembly of the F4 model.

The support description is tested in the ^{closed} guided test section by comparing the measured and calculated signatures. In this case, a description of the model-support system is used. Figure 13 shows the case of an ONERA standard model assembled ^{on} in a straight sting in the S3MA guided ^{rendered closed} ~~rendered~~ test section. A model ^{representation} with 20 doublets for the model and 15 for the sting provide a good agreement of the signatures.

Returning to the case of the F4 model in an S2MA transonic test section, figure 19 gives the Kp distributions on the line which the fuselage axis would occupy for various wall porosities.

We should insist on the relative magnitude of the wall effects and sting interferences. In the case of an S2MA wind tunnel (figure 20), in the perforated wall version with maximum ^{porosity} rate, the incidence corrections are zero. The drag corrections resulting from the longitudinal gradients promoted on the support sting and the wall effects are in a 3 to 4 ratio for a civilian aircraft model. The sting interference is more crucial for military aircraft models whose incidences may exceed 40 degrees (and even higher for missiles) [35,36]. Given these high values and the stresses to contain, the volumes of model support mechanisms are such that the wall effects for a well ^{proportioned} conditioned test section may seem secondary. This real problem, in the absence of a magnetic suspension, deserves to be considered first for future ^{adaptive} active wall wind tunnels.

2.3 APPLICATION TO INDUSTRIAL TESTING

We now have correct descriptions of models and its supports and of the test section porosity laws. As of now, the corrections

are all calculated prior to testing for a specific ^{test} case ^{defined by the} of a test section, wall configuration, supports, ^{and} model.

These corrections (figure 21) include four parts:

-corrections relative to an empty test section obtained from ^{measurements} corrected soundings, if necessary, and from the influence of the probe support,

-calculated or measured support interferences,

-corrections ^{for} of wall effects and of the ^{influence} field ^{impact} of the model on the test reference ^{tests}.

^{flowfield}
In all the computer calculations provide a set of corrections depending on M , C_x , C_z (or incidence) expressed in the form of a table or polynomial laws which ^{can be} introduced in the wind tunnel calculations to obtained real time corrected results. The correction calculations also provide the total ^{flowfield generated} field ^{as well as} promoted by the walls and supports, ^{number} for a Mach distribution and incidence correction ^{at} on any point ^{on} of the model. It is easy to know the ^{twist} spin and camber corrections of the ^{flow generated} wind promoted by the walls and the local Mach M and tail unit setting corrections due to the model supports.

^{number}
CONCLUSION

/14

The advantage of pressure measurements on the walls of test sections ^{has been} was clearly established for calculations of wall effects. For reasons of convenience, associated with the intended use of wind tunnels, these pressure measurements are ~~still~~ performed:

^{3D}
-occasionally in 3d to control the concept of uniform porosity of perforated walls and ^{to} check the mathematical descriptions of models and supports in a guided ^{closed} test section,

-systematically in 2D for direct access to corrections,

-imperatively in test sections with adaptive walls,

-finally with ^{care} ~~suspicion~~ in test sections with slotted walls. The measurements should be performed at a distance from the walls which is ^{physically} ~~technologically~~ difficult to do.

If the advantage of additional measurements of the other component of the local flow on control surfaces is to eliminate any model description, a real problem of measurement precision has not yet been solved.

Optimized test configurations (test section, sting, model) is the result of a compromise between wind tunnel investments, the cost of testing and the quickness with which the results prepared are ^{corrected} ~~rectified~~. In three-dimensional cases, the wall effect levels are reduced by limitations in model size due to the span for civilian aircraft, ^{and} due to the length for high incidence military aircraft. Small displacements of flexible walls will require greater accuracy in pressure measurements and in the positions of wall ^{3D} adaptive actuators. Test sections with 3D adaptive walls are still too recent to know their application limits and operating difficulties.

Meanwhile, it is suggested to use adaptations to the main ^{important} ~~point~~ of a test program. These adaptations may concern:

-models whose manufacturing specifications account for distortions in the flow of conventional walls (as practiced for aeroelasticity);

-walls which should meet specifications using conventional padding whether or not associated with improved ventilation distributions.

In any case, continuous revisions of concepts for minimizing wall effects should follow improvements in the specifications for precision required by manufacturers.

REFERENCES

1. L. McKinney, "Operational Experience with the National Transonic Facility", AGARD, Cesme ~~1983~~. ^{SEPTEMBER 1983}
CP-348
2. R. North, ^{et al} and ~~Alri~~, "Status Report on the European Transonic Wind Tunnel ETW" AGARD, Cesme ~~1983~~. ^{SEPTEMBER 1983}
CP-348
3. R. Dietz, "Wind Tunnel Capability Related to Test Section, Cryogenics and Computer-Wind tunnel Integration", AGARD-AR - 174 April 1982.
- ✓ 4. A. ^{Elsenaar} El-Senaar, E. Stanewsky, "A Report of GARTEUR Action Group on "Two Dimensional Transonic Testing Methods", AGARD CP 335-5 September 1982.
5. Wall Interference in Wind Tunnels Fluid Dynamics Panel Specialists Meeting", London 19-20, May 1982, AGARD CP 335.
- 6. T. Bignon, X. Vaucheret, X. Bouis, "Progress in Wind Tunnel Test Techniques and in the Corrections and Analysis of the Results", AGARD CP 339 - February 1983.
7. J.P. Chevallier, "Survey of the ONERA Activities on the Adaptive Walls Applications and Computation of Residual Corrections", Wind Tunnel Wall Interference Assessment/Correction Workshop NASA Langley 25-26 January 1983.
- 8. T. Bignon, E. Kraft, "A Review and an Update of GDP Specialists Meeting (London) on Wall Interference in Wind Tunnels", AGARD CPP 348-6 - August 1983.
- 9. L. Parker, J. Erickson, "Development of a Three-Dimensional Adaptive Wall Test Section with Perforated Walls", AGARD CP 335-17, 1982.
10. E. Schairer, J. Mendoza, "Adaptive Wall Wind Tunnel Research at AMES Research Center", AGARD CP 335-16, 1982.
11. S.W.D. Wolf, I. Cook, M. Goodyer, "The Status of Two and Three-Dimensional Testing in the University of Southampton Transonic Self-Stream Lining Wind Tunnel" AGARD CP 335-15, 1982.
- 12. V. Ganzer, "On the Use of Adaptive Walls for Transonic Wind Tunnel" AGARD CP 335 - 13 - 1982.
13. Mignosi, Dor, Gobert, "Results of Cryogenic Tests at T2", Report to 20th AAF Symposium, November 1983.
- 14. Archambaud, Seraudie, "Studies of Adaptive walls With T2", Report at 20th AAF Symposium, November 1983.

- 15 - F. Chevallier, A. Mignosi, J. Archambaud, A. Seraudie,
 "Adaptive Walls on a T2 Wind Tunnel. ^{Effects} Principle, Construc-
 tion and ~~a Few Examples of Two-Dimensional Results~~ Aero-
 spatiale Research no. 1983-4 - July 1984 ^{Some Typical}
- 16 - J. Coulomb, "Clinometric Soundings ^{Measurements} Downstream from a Profile ^{Model}
 Between Walls. DRET/CEAT Summary Report 83/1013, August 29,
 1983.
17. J. Chevallier, "Three-dimensional ^{Effects} Tests on Profiles", 18th
 Symposium of Applied Aerodynamics by AAAF Positions, November
 1981.
18. J.P. Archambaud, J. Chevallier, "Use of Adaptive Walls for
~~Flat Current Testing~~", AGARD CP 335-14, 1982 ^{May 1982}
^{in Two-Dimensional Tests}
19. C. Capelier, J. Chevallier, F. Bouniol, "New Method of Cor-
 recting Wall Effects in ~~a Flat Current~~", 14th Symposium of
 Applied Aerodynamics. ^{Effects} Toulouse 7/9 November 1977 and R.A.
 no. 1 - 1978. ^{Two-Dimensional Tests}
20. M.C. Firmin, P. Cook, "Disturbances from Ventilated Tunnel
 Walls in Airfoil Testing", AGARD CPP 348-8. August 1983.
21. W. Kemp, "Transonic Assessment of Two-Dimensional Wind Tunnel
 Wall Interference Using Measured Wall Pressures", Advanced
 Technology Airfoil Research. NASA Conf. ^{CP} Publ. 2045 - March
 1978.
22. H. Sawada, "An Experiment of Lift Interference on 2D Wings
 in a Wind Tunnel With Perforated Walls", Trans Japan Soc.
 Aerospace Sci. Vol.22 - 1980 pp. 181-202.
23. M. Mokry, L. Ohmann, "Application of the Fast Fourier Trans-
 form to ~~Two Dimensional~~ Wind Tunnel Wall Interference",
~~J. Of Aircraft~~, Vol.17, June 1980, pp 402-408.
24. M. Mokry, "Evaluation of Transonic Wall Interference Correc-
 tions From Measured Wall Pressures", AGARD ^{of} Working Group.
 NASA Langley 13/14 March 1980.
25. J. Smith, "A Method For Determining 2D Wall Interference on
 an Airfoil From Measured Pressure Distributions Near the Walls
 and on the Model. NLR TR 81016 U 1981.
26. J. ^{Smith} SMith, "Measured Boundary Conditions Methods for ^{2D} Flow",
 AGARD CP 335-9 - September 1982.
27. P. Ashill, D. Weeks, "A Method for Determining Wall Inter-
 ference Corrections in Solid Wall Tunnels From Measurements
 of Static Pressure at the Walls", AGARD - CP 335-1 - Sep-
 tember ^{May} 1982.
- 28 - J. Paquet, "Disturbances Caused by the Walls of a Wind Tunnel.
 Integral Method", Phd-Engineering Thesis, University of Lille
 6/26/83. ^{Ph.D.}

29. F. Steinle, E. Stane^wsky, "Wind Tunnel Flow Quality and Data Accuracy Requirements", AGARD AR 184 November 1982.
30. P. Poisson-Quinton, "Ground /Flight Test Techniques and Correlation", AGARD FDP Meeting, Cesme Sept. 1983.
31. X. Vaucheret, "Corrections of Transonic Wind Tunnel Walls - Equivalent Porosity", ONERA - Publication No. 1977-3.
32. X. Vaucheret, "Reevaluation of the Corrected Results of the S3MA CAST 7 Profile. Appendix to: A Report of a GARTEUR ACTION GROUP ON TWO Dimensional Transonic Testing Methods", AGARD CP - 335 - London - May 1982.
33. J. Fiat, "Calculation of Lifting Surfaces in the Presence of Nonlifting Bodies in Perfect Incompressible Flows Using the Singularities Method", CNAM Engineering Thesis - Paris 1982.
34. X. Vaucheret, "Improvement to the Calculation of Wall Effects in ONERA Industrial Wind Tunnels", AGARD CP - 335 - ~~London~~ May 1982.
35. L. Ericsson, J. Reding, "Practical Solutions To Simulation Difficulties in Subscale Wind Tunnels Tests", AGARD CP 348 - CESME - Sept. 1983.
Cesme
36. X. Vaucheret, "Improvements in Solving the Problems Encountered during High Incidence Testing of Models in Wind Tunnels", AGARD-R-692 - Munich - May 1980.
37. H. Sawada, "A new Method of Estimating Wind Tunnel Wall Interference in the Unsteady Two Dimensional Flow", NAE AN 9 NRC 21274 - January 1983.

Table 1
Wind Tunnels With Controlled 2D Boundary Conditions

Wind Tunnel	Location	Test Section Section: b/H	Length/H	Boundary Conditions Control Nb Points	(paths, Threshold/H	Model C/H
T.S.W.T.	University of South-Hampton	$15 \times 15 \text{ cm}^2$	7.33	20 actuators		0.6 to 1
T.U.B.	Technical University of Berlin	$15 \times 15 \text{ cm}^2$	4.6	8 actuators	$\pm 0.16 \cdot 10^{-4}$	0.66
T ₂	ONERA-CERT Toulouse	$39 \times 37 \text{ cm}^2$	3.5	16 actuators	$0.07 \cdot 10^{-4}$	0.3 to 0.5
CALSPAN AEDC	Buffalo Tulahoma	$25 \times 30 \text{ cm}^2$	4.6	10 boxes (perforated walls)	Longitudinal Tubes 0.3°	0.3 to 0.5
NASA Ames	California	$25 \times 13 \text{ cm}^2$	5.66	3x6 boxes (slotted holes)	Laser Velocimetry over two 0.05° planes	0.6

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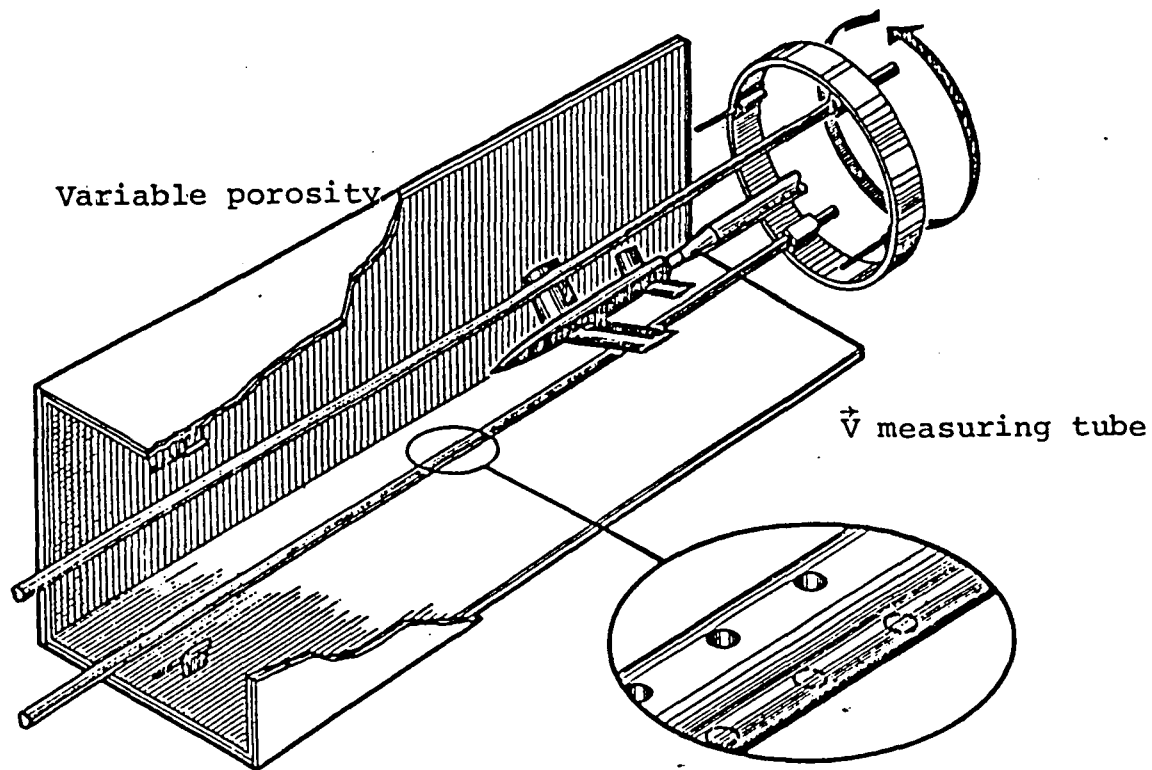
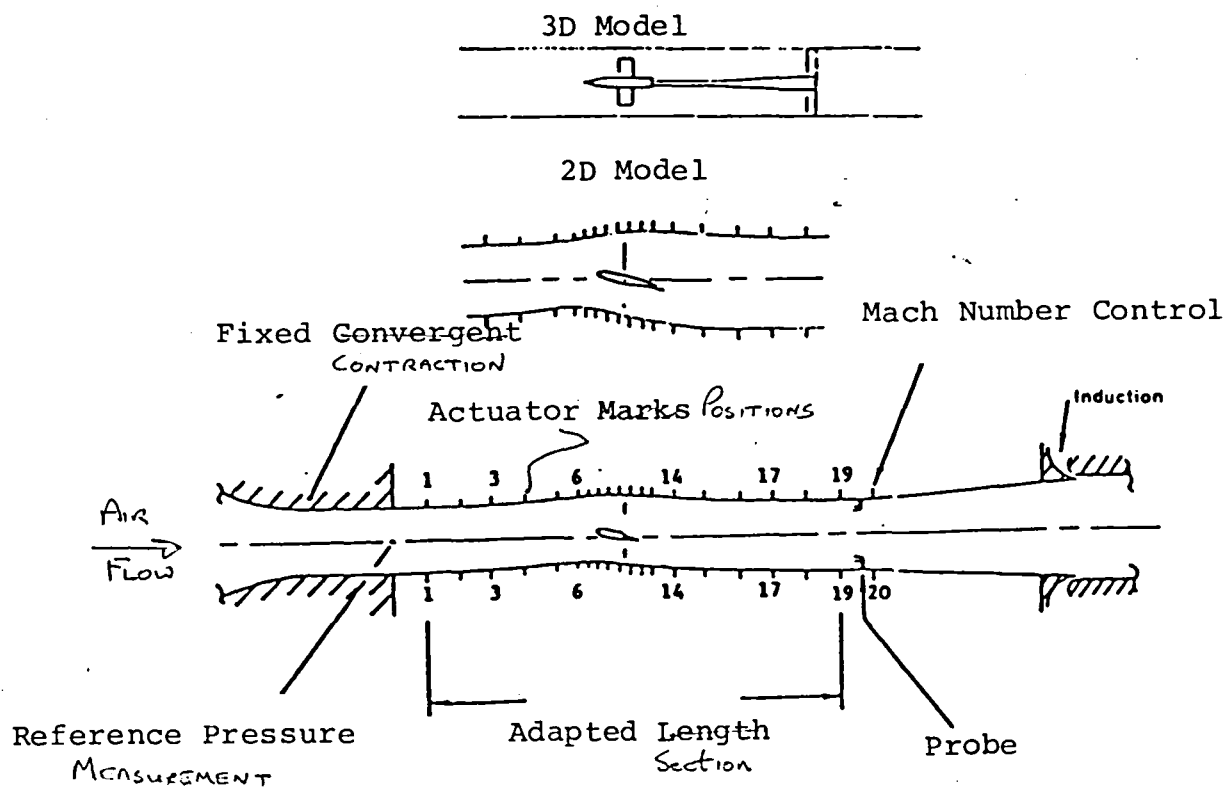


Fig. 1 - A.E.D.C. 1T TUNNEL



TSWT at
Fig. 2 - Wind Tunnel of Southampton University, UK.

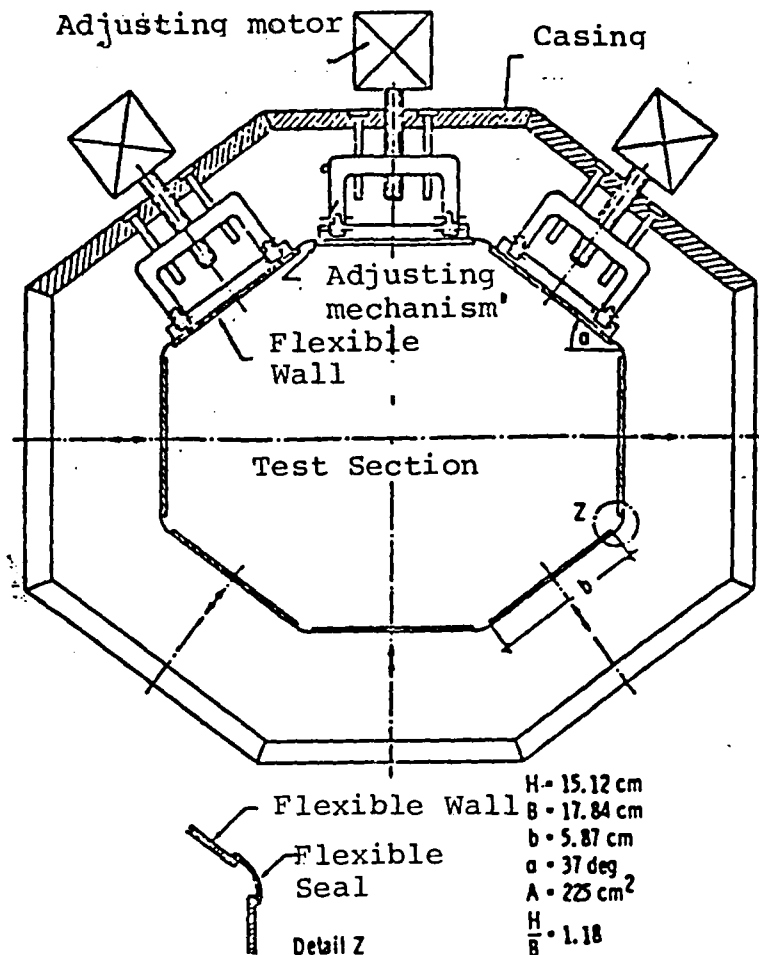


Fig. 3 - *Technical* University of Berlin Wind Tunnel

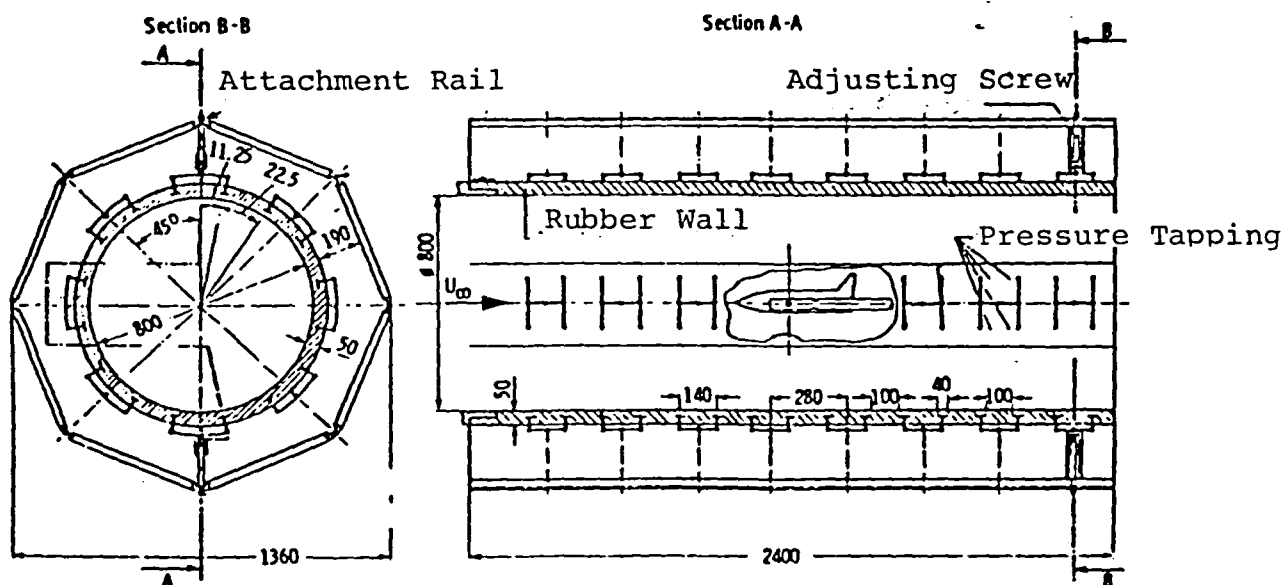


Fig. 4 - DFVLR Test Section Project with Elastic Walls
rubber

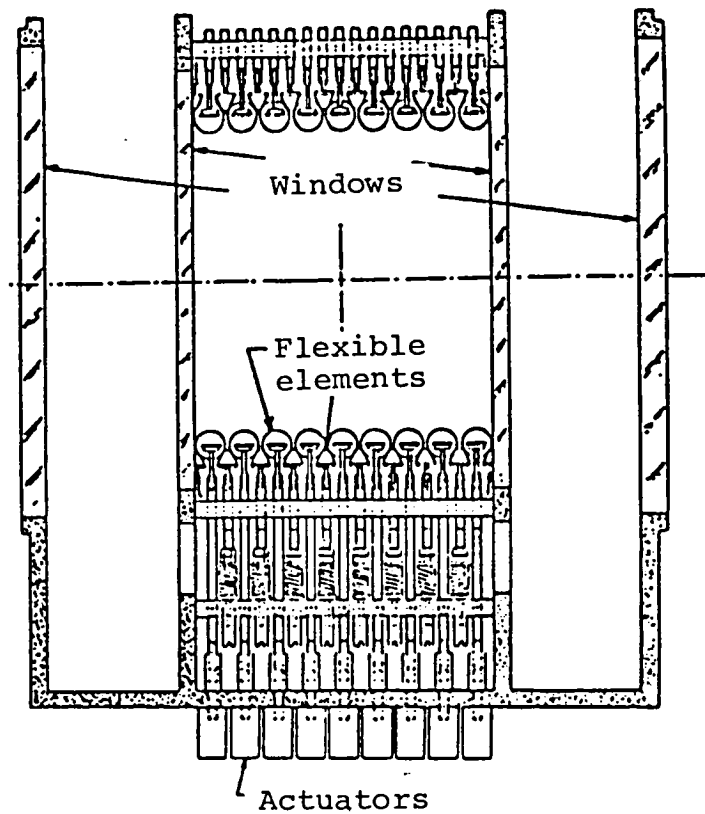


Fig. 5 - AFFDL Pilot Wind Tunnel With Flexible Wall Elements(Rods)

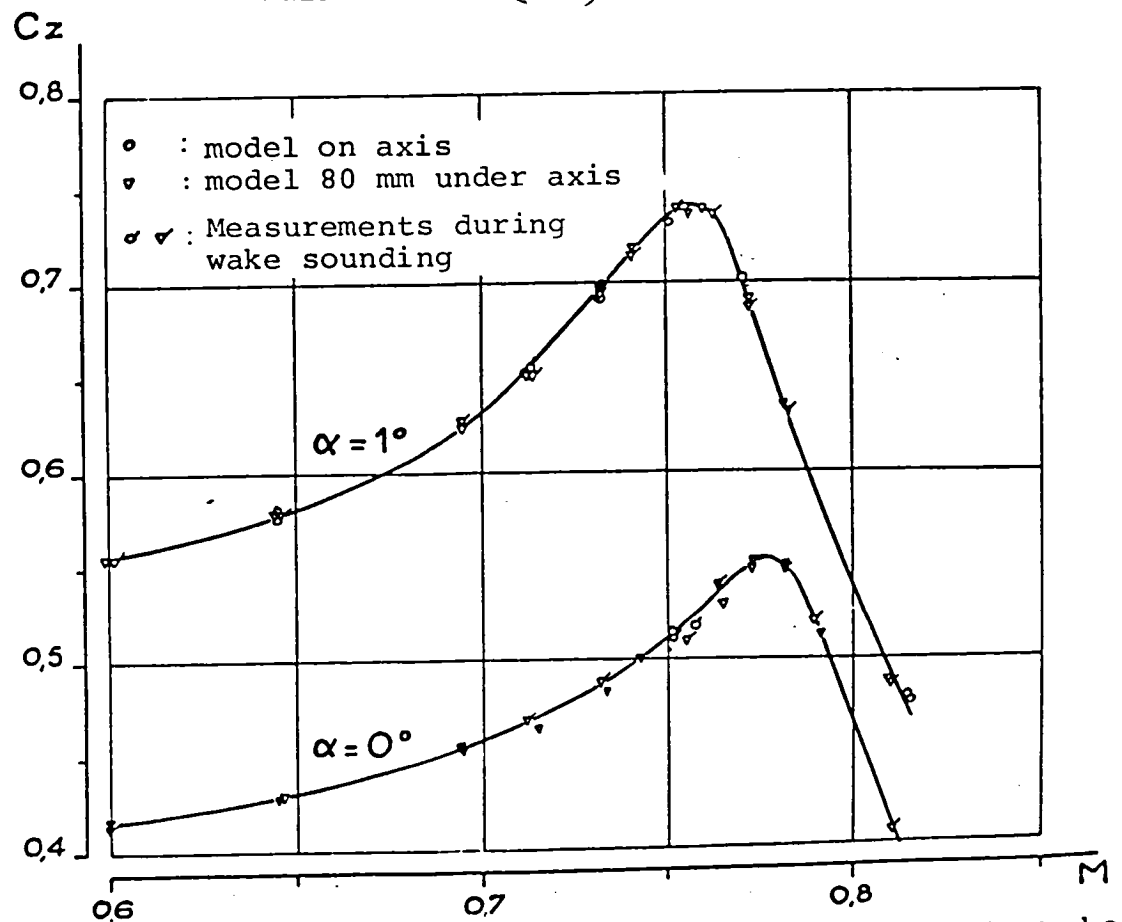


Fig. 6 - CAST 7 Profile. Lift as a Function of Mach Number

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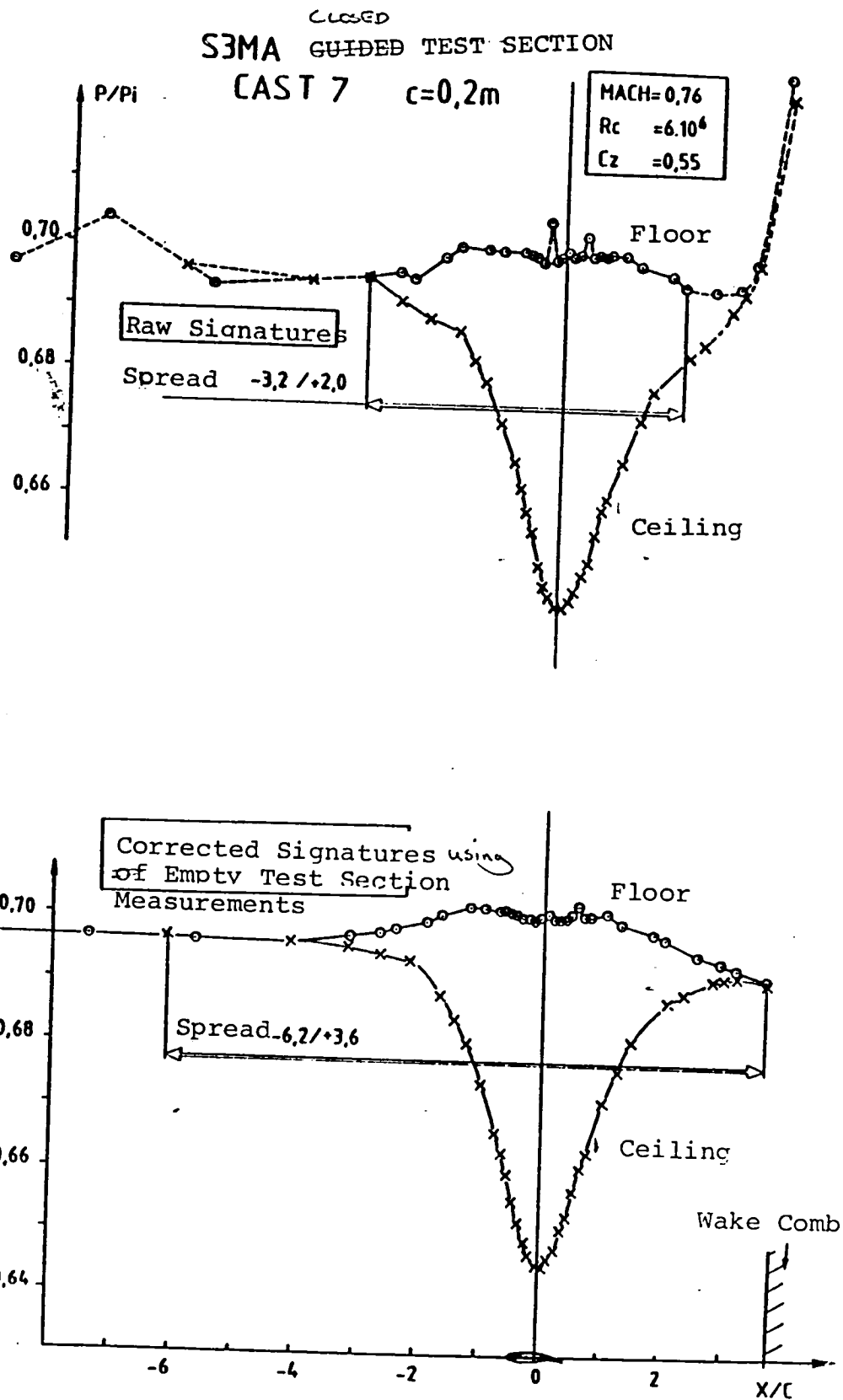


Fig. 8 - 2D - Rough and Corrected Signatures of Empty Test Section

S3MA
CAST 7

Closed
GUIDED TEST
SECTION
 $c = 0,2 \text{ m}$
 $M = 0,76$
 $Rc = 6.10^6$

— Experimental
- - - Theoretical

LIFT TERMS

blockage
LOCK TERMS

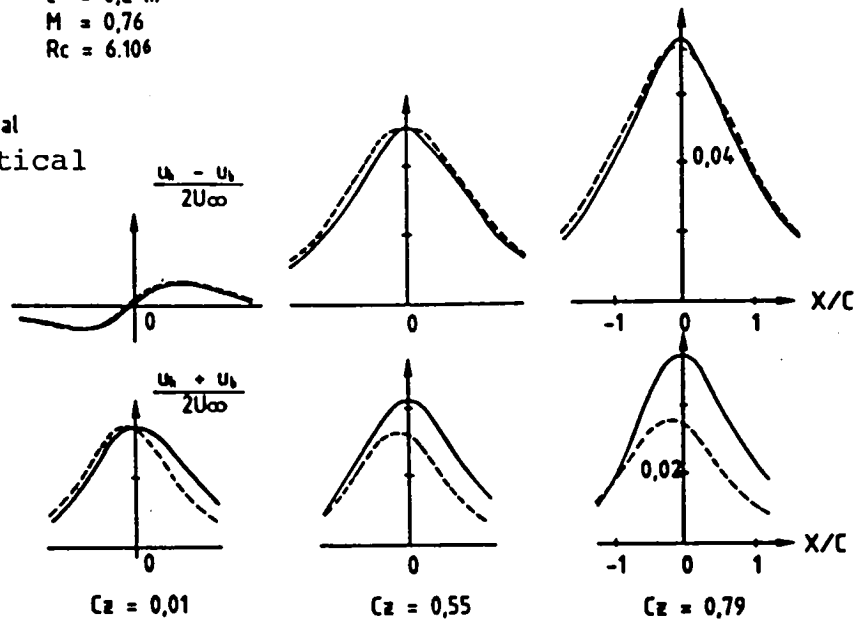


Fig. 9 - 2D Comparison of Calculated and Measured Signatures

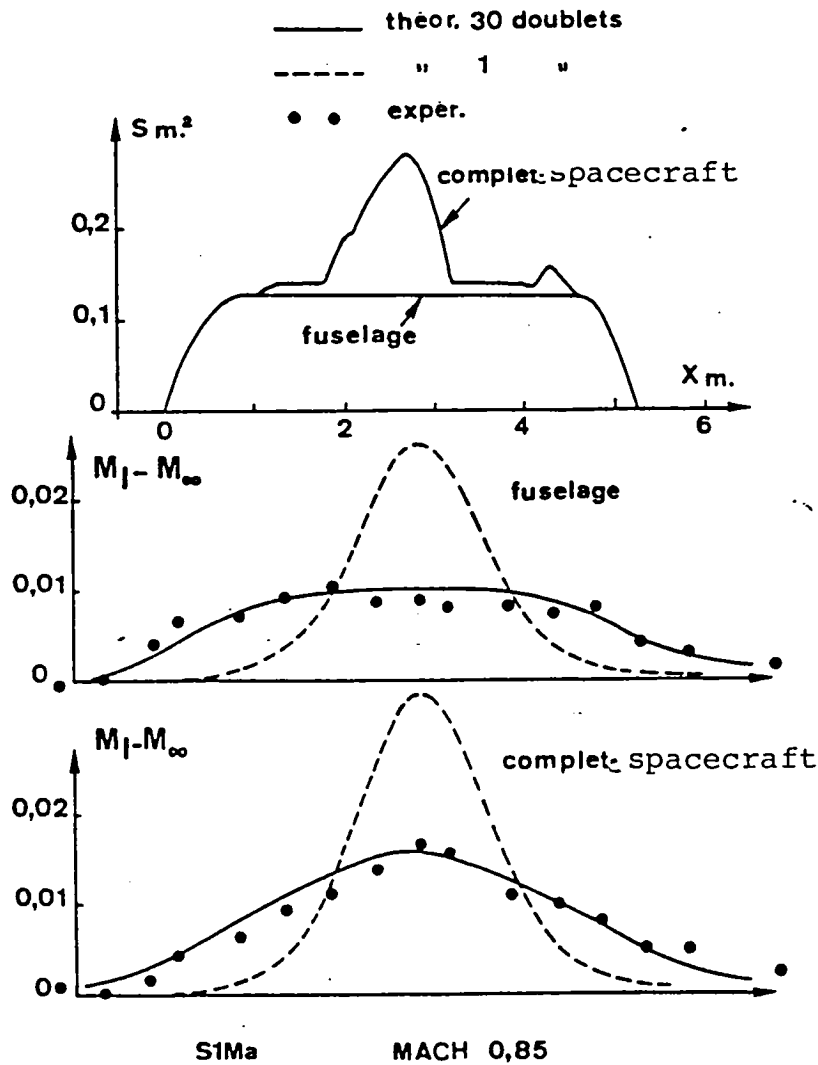


Fig. 10 - 3D Signatures on Solid Walls

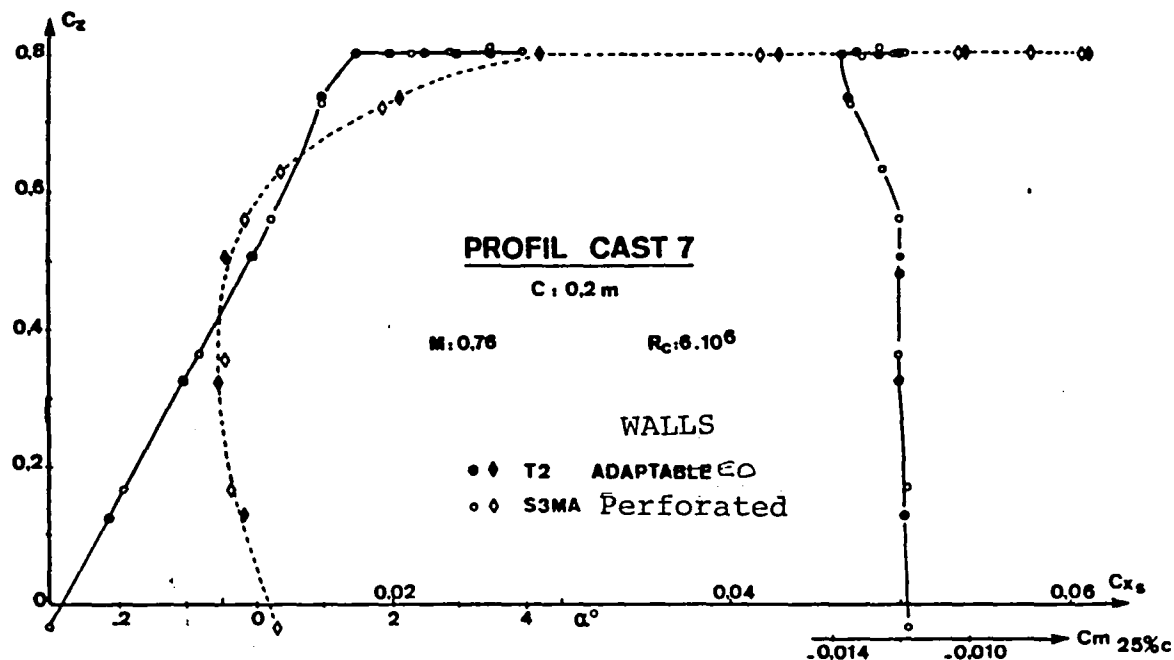


Fig. 11 - CAST 7 Profile - Comparison S3MA-T2 Results

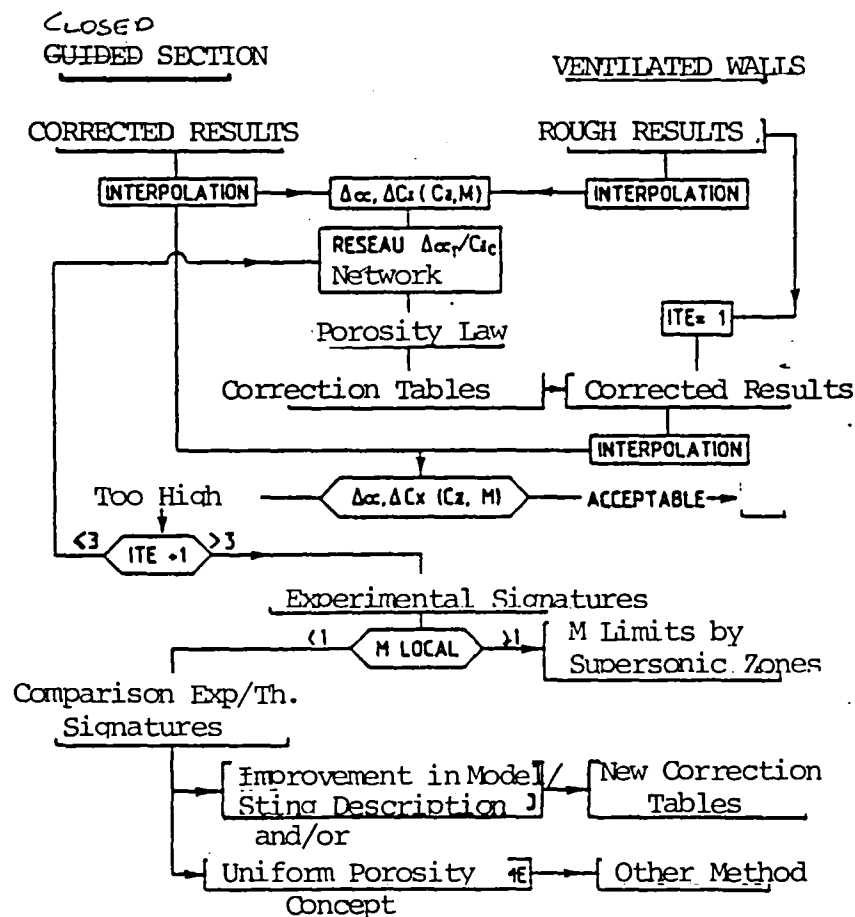


Fig. 12 - Determination of the Porosity Laws of a Test Section With Ventiladed Walls.

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